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THE REFLECTION EFFECT IN ECLIPSING BINARY SYSTEMS

ZDENĚK KOPAL

ABSTRACT

It is pointed out that the discrepancies between the observed amounts of light reflected in eclipsing binary systems and those calculated with the aid of Eddington's formula are due to the neglect of bolometric corrections. The discrepancies turn out to provide us with a possibility of determining the temperature of the reflecting layer. The effect of reflection on the apparent ellipticity constant is studied on the basis of formulae by Milne (taking account of the darkening) and Pike; in general, the correction term is found to be positive and proportional to the sum of light reflected by both components.

The phenomenon known as the reflection effect was first noted and correctly explained by R. S. Dugan[1] in 1908 in his study of RT Persei; two years later it was independently discovered and explained by J. Stebbins[2] and C. Nordmann.[3] Since then the reflection effect has been observed in a number of other systems and has been the subject of several theoretical investigations. Calculations of its magnitude and its variations with phase have been undertaken by J. Stebbins,[4] A. S. Eddington,[5] E. A. Milne,[6] E. W. Pike,[7] and W. Krat,[8] but the theories thus far developed have never attained sufficient agreement with the observations.

[1] *Science*, **28**, 854, 1908; *Princeton Contr.* No. 1.

[2] *Ap. J.*, **32**, 213, 1910.

[3] *Bull. Astr.*, **27**, 145, 1910.

[4] *Seeliger Festschrift*, p. 422, 1924.

[5] *M.N.*, **86**, 320, 1926.

[6] *M.N.*, **87**, 43, 1927.

[7] *Ap. J.*, **73**, 205, 1931.

[8] *M.N.*, **94**, 70, 1933.

The present paper consists of two main parts. In the first we shall deal with the magnitude of the effect in full phase and shall show that the discrepancies between observations and Eddington's theory furnish us with a possible means of determining the temperature of the reflecting layers. The second part will be devoted to the problem of variation of the reflection with the phase, with special reference to its possible effect on the apparent ellipticities taken from the light-curves.

I. THE REFLECTION IN FULL PHASE

Stebbins carried out his investigation under the assumption that the effect was due to diffuse reflection of light from the stellar photosphere, following Lambert's law (or the more complicated Lommel-Seeliger law). Eddington pointed out the important fact that the reflection must be due to re-emission of the incident radiation and that for a star in a steady state the heat albedo must necessarily be unity.[9] For the amount of simple reflection in full phase Eddington gave the formula

$$L_j^*(0) = \tfrac{2}{3}K_j L_i \left\{ \sin^2\phi_j + \frac{2 + \cos^3\phi_j - 3\cos\phi_j}{\sin\phi_j} \right\} , \qquad (1)$$

where $\sin\phi_j$ is the radius of the reflecting star r_j expressed in terms of the orbital radius as unity, L_i is the luminosity of the primary (total luminosity of the system taken as unity), and

$$K_j = \frac{1 - \frac{1}{4}a_j}{1 - \frac{1}{3}a_j} ,$$

a_j being the coefficient of darkening. As one may easily verify, the foregoing formula is somewhat insensitive to the darkening. If we assume uniform disks, $K = 1$, whereas in case of complete darkening $K = 9/8$. Developing (1) in powers of r, we get

$$L_j^*(0) = \tfrac{2}{3}K_j L_i \{ r_j^2 + \tfrac{1}{4}r_j^3 - \tfrac{1}{64}r_j^7 - \tfrac{13}{512}r_j^9 + \ldots \} , \qquad (1.1)$$

i.e., we see that in not too close pairs, where the quantities of the order r^7 and higher are negligible, the two first terms give the amount of reflected light with a sufficient degree of accuracy.

[9] Eddington, *op. cit.;* for the general argument cf. also Milne, *op. cit.*, p. 44.

In applying his formula to practical cases, however, Eddington found discrepancies which could not be attributed to observational errors.[10] Krat, using Eddington's formula, found later that, in systems with secondaries of low temperature, the calculated amounts of re-radiated light were in almost every case too high compared with the observed reflection.[11] The reason for this is not difficult to find. The amount of reflection calculated from (1) corresponds, according to the definition of the heat albedo as unity, to a bolometric scale, and, if the temperature at which the light is re-radiated (i.e., approximately the effective temperature of the reflecting star) is not the same as that of the primary, the visual efficiency of the reflected light might be different from that of the incident radiation. Thus, on the basis of (1), we are in a position, from the discrepancy between the observed and calculated reflection, to determine the temperature of the reflecting star, provided the temperature of the incident radiation is known.

The following tables will illustrate the point. Table 1 contains all systems displaying appreciable reflection effect for which the elements are reliably known. Columns 5 and 6 give the spectra of the components, either observed or computed from the ratio of surface brightnesses on the assumption of black-body radiation; the latter are inclosed in brackets. Column 7 gives the amount of observed reflection, $2c$, c being the usual reflection constant taken from the rectification of the light-curve; and column 8 gives the theoretical reflection as computed by equation (1). As is readily seen, observations and theory differ widely in most of the systems listed.

The second column of Table 2 contains the values ΔM defined as

$$\Delta M = \tfrac{5}{2} \log \frac{L^*(0)_{\text{calc}}}{L^*(0)_{\text{obs}}} ,$$

the bolometric corrections depending only on the temperatures of both components. If the temperature of the primary is known from its spectrum, we can determine from ΔM the temperature of the secondary. Columns 3 and 4 contain the logarithms of temperature

[10] *Op. cit.*, p. 324; cf. also *The Internal Constitution of the Stars*, p. 213, 1926.

[11] *Op. cit.*, p. 74, Table 3.

TABLE 1*

Star	L_1	r_1	r_2	Sp_1	Sp_2	$2c$	$L_2^*(0)_{calc}$	Authority
Y Cam..	0.950	0.213	0.234	A0	(F3)	0.041	0.037	Dugan, *Princeton Contr.*, No. 6
RZ Cas..	.877	.225	.291	A2	(G3)	.063	.053	*Ibid.*, No. 4
TV Cas..	.859	.276	.298	B9	(F5)	.074	.055	McDiarmid, *Princeton Contr.*, No. 7
R CMa..	.934	.248	.239	F0	(K3)	.015	.038	Dugan, *Princeton Contr.*, No. 6
RS CVn.	.690	.087	.289	F4	G8	.034	.042	Sitterly, *Princeton Contr.*, No. 11
U Cep...	.839	.194	.313	A0	(G7)	.043	.059	Dugan, *Princeton Contr.*, No. 5
Z Dra...	.911	.217	.270	A5	(G7)	.032	.047	*Ibid.*, No. 2
SZ Her..	.800	.321	.334	A3	(F1)	.030	.065	*Ibid.*, No. 6
RV Oph.	.825	.125	.203	A0	(G2)	.018	.024	*Ibid.*, No. 4
RT Per..	.863	.275	.275	F2	(G5)	.022	.049	*Ibid.*, No. 1
β Per...	.895	.210	.239	B8	(G4)	.045	.036	Stebbins, *Ap. J.*, **32**, 185
X Tri...	.867	.285	.328	A3	G5	.018	.067	Dugan, *Princeton Contr.*, No. 8
W UMi.	.890	.370	.322	A0	(F6)	.038	.061	*Ibid.*, No. 10
RS Vul..	0.922	0.307	0.219	B8	(B9)	0.078	0.032	Krat, *NNVS*, **4**, 413

* For ellipsoidal stars the given radii are geometric means of the semi-axes. All solutions are "uniform," with the exception of that for X Tri, where one-third darkening was assumed.

TABLE 2

Star	ΔM	$\log T_{1\mathrm{eff}}$	$\log T_{2\mathrm{eff}}$	$\log T_{2\mathrm{refl}}$	$\frac{L_1^*(0)}{L_2^*(0)}$	$2c_{\mathrm{theor}}$	O−C
Y Cam.........	−0.11	4.04	3.69	3.66	0.04	0.036	+0.005
RZ Cas.........	−0.19	4.00	3.77	3.76	.08	.059	+ .004
TV Cas.........	−0.17	4.07	3.81	3.67	.15	.066	+ .008
R CMa.........	+1.01	3.87	3.63	3.55	.08	.021	+ .006
RS CVn........	+0.23	3.82	3.72	3.70	.04	.037	− .003
U Cep.........	+0.34	4.04	3.72	3.60	.07	.038	+ .005
Z Dra..........	+0.42	3.93	3.67	3.64	.06	.037	− .005
SZ Her.........	+0.77	3.98	3.86	3.56	.23	.038	− .008
RV Oph........	+0.31	4.04	3.77	3.61	.08	.020	− .002
RT Per.........	+0.87	3.86	3.76	3.58	.16	.030	+ .008
β Per	−0.24	4.10	3.75	3.66	.09	.045	.000
X Tri..........	+1.43	3.97	3.74	3.51	.12	.029	− .009
W UMi.........	+0.26	4.04	3.81	3.62	.16	.046	− .008
RS Vul.........	−0.97	4.14	4.06	3.90	0.16	0.067	+0.011

of the primary and secondary as inferred from their spectra, according to the temperature scale given by Russell, Dugan, and Stewart;[12] and column 5 contains the logarithms of T_2 deduced from the bolometric corrections.[13]

One would expect that, if the foregoing procedure were right, the values of the columns 4 and 5 should agree (or perhaps differ by a constant quantity); manifestly this is not the case. But it may admit of a simple explanation. Thus far we have considered that the observed reflection is due to the secondary alone and have neglected

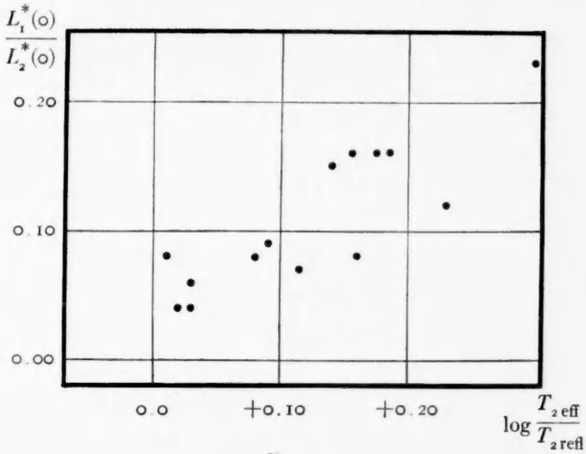


Fig. 1

altogether the radiation possibly reflected by the primary. But in practice we have to deal always with the combined reflection, and its observed amount is only the difference in light reflected by the primary and the secondary, respectively. One would, consequently, expect that the discrepancies between the effective and the reflection temperatures of the secondary would depend on the ratio $L_1^*(0)/L_2^*(0)$, the values of which were calculated with the aid of equation (1) and are given in column 6 of Table 2. If these are plotted against the corresponding temperature differences, a glance at the diagram will show that this is exactly the case and that, with decreasing $L_1^*(0)/L_2^*(0)$, the discrepancies between the temperatures

[12] *Astronomy*, **2**, 753.

[13] Cf. *The Internal Constitution of the Stars*, p. 139, Table 16 (due to Hertzsprung).

diminish; thus the disagreement between the observed and the calculated amounts of reflection can be removed if attention is paid to proper bolometric corrections, the exact formulae being

$$\left.\begin{aligned} L_1^*(0) &= \frac{4-\alpha_1}{2(3-\alpha_1)} L_2 \{r_1^2 + \tfrac{1}{4}r_1^3 + \ldots\} \exp 0.15[\Delta(T_1) - \Delta(T_2)]\,, \\ L_2^*(0) &= \frac{4-\alpha_2}{2(3-\alpha_2)} L_1 \{r_2^2 + \tfrac{1}{4}r_2^3 + \ldots\} \exp 0.15[\Delta(T_2) - \Delta(T_1)]\,, \end{aligned}\right\} \quad (2)$$

where the $\Delta(T_i)$'s are the corresponding bolometric corrections. Using equations (2) we can now evaluate the amounts of light re-radiated by both components, and, by forming their differences, we can predict the observed reflection coefficients. This was done, and the results are contained in column 7. A glance at the last column giving the differences O − C shows that they are not systematic and that none exceeds the limits of observational errors. The agreement between the theory and the observations is therefore to be regarded as practically complete.[14]

A closer look at the foregoing diagram reveals one more interesting feature. Extrapolating the relation between the difference in temperature and $L_1^*(0)/L_2^*(0)$ down to $L_1^*(0)/L_2^* = 0$, we see that even in case of reflection by the secondary only, the temperatures do not agree exactly, the temperature deduced from the reflection effect being about 10 per cent higher than the effective temperature—a heating effect of the incident radiation predicted by Milne[15] and checked observationally.

II. THE EFFECT OF THE REFLECTION ON THE APPARENT ELLIPTICITY

Eddington assumed the reflection to vary with the phase according to the formula

$$f(\theta) = \frac{\sin\theta - \theta\cos\theta}{\pi}\,, \qquad (3)$$

[14] A possible explanation of further discrepancies, if any, might still be that a part of the incident radiation can be re-radiated as luminescence radiation in bright lines. Walter's recent careful analysis of reflection in the system ζ Aurigae (*Zs. f. Ap.*, **14**, 62, 1937) has shown that the intensity of the emission *Ca* II lines follows closely the phase of reflection. The amount of light re-radiated in this way may, however, be always very small.

[15] *Op. cit.*, p. 48.

θ being the phase angle measured from the primary minimum. This is the well-known expression frequently used for computing the luminosity changes of inner planets with the phase.[16] It follows from (3) that the whole amount of reflection will vary as

$$L_1^*(0)\,\frac{\sin\theta-(\theta-\pi)\cos\theta}{\pi}+L_2^*(0)\,\frac{\sin\theta-\theta\cos\theta}{\pi}\,.$$

As may be easily verified, $f(\theta)$ is a single valued function of θ in the interval $0<\theta<\pi$;[17] if we expand it in a Fourier series and verify that

$$\frac{2}{\pi}\int_0^\pi\theta\cos^2\theta\,d\theta=\frac{\pi}{2}\,,$$

$$\frac{2}{\pi}\int_0^\pi\theta\cos\theta\cos2\theta\,d\theta=-\frac{20}{9\pi}\,,$$

the coefficients of $\cos\theta$ and $\cos 2\theta$ take the forms

$$\tfrac{1}{2}[L_1^*(0)-L_2^*(0)]\cos\theta+\frac{20}{9\pi^2}[L_1^*(0)+L_2^*(0)]\cos2\theta+\ldots\ldots \quad (4)$$

The coefficient of $\cos\theta$ is the well-known reflection constant and is proportional to the difference in light reflected by each component; the coefficient of $\cos 2\theta$ is proportional to their sum.

Eddington pointed out that the coefficient of $\cos 2\theta$ due to reflection is likely to mask to some extent the apparent ellipticity of the system z, the true ellipticity being

$$\epsilon^2=\left\{z+\frac{40}{9\pi^2}[L_1^*(0)+L_2^*(0)]\right\}\operatorname{cosec}^2 i\,, \quad (5)$$

i.e., the true ellipticity should always be higher than the observed.[18] This is an important result, because the sum of the light reflected by

[16] See, e.g., E. Schoenberg, *Theoretische Photometrie* ("Handb. d. Astroph.," erste Hälfte, zweiter Teil), **1**, 64.

[17] Cf. *ibid.*, Appen., Table VI*a*.

[18] Eddington in his treatment gave the value $32/9\pi^2$, which I am unable to check. Also his statement that the additional term is proportional to the reflection constant was likely to lead (and did lead, in fact, cf. Dugan, *Princeton Contr.*, No. 13, p. 7) to

the two components, as their separation decreases, may become very considerable. Although the total amount of re-radiated light is unobservable itself, it may be fairly accurately predicted from the theory, and consequently one might expect that equation (5) could be applied in all practical cases. But it must be emphasized that its application would not be generally correct.

It is clear that the amount of correction depends entirely on the form of the variation of reflection with the phase, and it is proper to remember that equation (3) is valid only under rather limited conditions. First, it disregards completely the darkening. In our case this feature of the problem is still more complicated by the circumstance that the darkening of the incident and reflected radiation is quite different.[19] The effect of this on the phase variations has been thoroughly investigated by Milne, who found that, if the degree of darkening of the incident radiation $\alpha_1 = 0.6$ (i.e., the same as that of the sun), the reflection follows the phase law:

$$f(\theta) = \frac{24}{17}\left\{\frac{(1-\cos\theta)(1-3\cos\theta)}{32\cos\frac{1}{2}\theta}\log\frac{1+\cos\frac{1}{2}\theta}{\sin\frac{1}{2}\theta} + \frac{1+5\cos\theta}{16} + \frac{\sin\theta+(\pi-\theta)\cos\theta}{3\pi}\right\}. \tag{6}$$

The harmonic analysis of this complicated expression can proceed only numerically, yielding

$$0.5[L_1^*(0) - L_2^*(0)]\cos\theta + 0.207\,[L_1^*(0) + L_2^*(0)]\cos 2\theta + \ldots\ldots \tag{7}$$

The coefficient of $\cos 2\theta$ occurs again, but its value is about 10 per cent lower than that resulting from the neglect of the darkening.

A more serious defect of law (3) is that it is strictly valid only if the beam of incident light is parallel. This will be approximately true either if the components are very distant—but then the reflection

some misunderstandings. This is true if we consider the reflection by one component only (as Eddington did); but if we consider the combined reflection, then the reflection constant will be proportional to the difference in the light reflected by each component, whereas the coefficient of $\cos 2\theta$ is proportional to their sum. This has already been pointed out by Walter (*Königsberg Veröff.*, No. 2, p. 9).

[19] Milne, *op. cit.*, pp. 50–51; cf. also Pike, *op. cit.*, p. 214.

itself will be inappreciable—or if both components are equal in size. Only the latter case is of practical importance. Thus, equation (5) may be applied with confidence only to systems with the radii ratio equal to or very near to unity, and may lead to quite erroneous results if applied to systems where the components are very unequal.

In order to form an idea about the nature of the problem in this last case, let us make use of a formula recently suggested by Pike which is claimed to be a better approximation for close systems. Pike assumes the reflection to vary with the phase according to the law

$$L_1^*(0)\cos^{n_1}\frac{\theta}{2} + L_2^*(0)\sin^{n_2}\frac{\theta}{2}\,, \tag{8}$$

where n_1 and n_2 are functions of the radius of either component, tabulated by Pike within certain ranges. For well-separated systems, the n_i's are sensibly equal to 2, and increase with increasing r.

Analyzing the foregoing expression, we find that the coefficient of $\cos 2\theta$ will be of the form

$$\beta[\gamma_1 L_1^*(0) + \gamma_2 L_2^*(0)]\ ;$$

it depends again on the total amount of reflected light, but the γ_i's depend on r_1 and r_2, their exact values being

$$\beta = \sum_{k=2}^{\infty} \frac{(-1)^k (2k)!}{2^{2k-1}(k!)(k+2)!(k-2)!} = 0.1125\ldots\,,$$

$$\gamma_i = \sum_{k=2}^{\infty} \frac{\Pi\left(\frac{n_i}{2}\right)}{\Pi\left(\frac{n_i}{2} - k\right)}\,,$$

where Π denotes the Gauss function. Adopting the law of variation of the reflection with phase proposed by Pike, we see that the coefficient of $\cos 2\theta$ comes out, on the whole, smaller than that following from equation (3). Another interesting consequence of (8) is that, apart from the evident inequality of $\gamma_1 \neq \gamma_2$ for $r_1 \neq r_2$, the relationship between γ and n is not monotonic but of an oscillating character.

Summarizing the second part of the present paper, we conclude that the reflection is always superposed upon the effect of the ellipticity of a system, the true ellipticities being systematically higher than those directly obtained from the light-curves. The disturbing effect of the reflection is proportional to the sum of light reflected by each component. If the components are equal in size, the effect of the reflection can be taken into account, but for very unequal systems the amount of allowance due remains uncertain.

It is my pleasure to express to Dr. Harlow Shapley my appreciation for the opportunity of working at the Harvard College Observatory, where this study was carried out.

HARVARD COLLEGE OBSERVATORY
December 1938

SPECTROGRAPHIC ELEMENTS FOR β CAPRICORNI*

ROSCOE F. SANFORD

ABSTRACT

Observations.—Spectrograms of β Capricorni taken at Mount Wilson prolong the interval of observation of this star to about forty years. The Mount Wilson observations, through their greater extension to the ultraviolet, have revealed a short-period spectroscopic binary as the real secondary to the primary already studied and discussed by Merrill and by H. Spencer Jones.

Orbits.—It has been possible, first, to improve all the elements of the primary, especially the period; second, to get the semiamplitude of velocity variation of the center of mass of the short-period binary; and third, to derive elements for the principal star of the short-period binary. The two periods involved are 1374 and $8\frac{2}{3}$ days. Elements and functions depending upon them are given in Tables 2 and 6.

Masses.—The masses of the three stars cannot be less than 4.4, 3.9, and 0.9 $\odot$. How much they exceed these values depends upon the inclinations of the two orbit planes. Considerations of mass, luminosity, and spectral type seem to indicate that the inclinations probably do not differ much from 90°.

W. W. Campbell[1] announced the radial-velocity variation of β Capricorni in 1899. Forty-five spectrograms accumulated at the Lick Observatory by 1908 yielded the velocities from which P. W. Merrill[2] derived a set of elements for the spectrographic orbit of the primary star.

Another series of seventeen spectrograms obtained at the Cape Observatory between 1908 and 1912 extends the interval of observation another three years. H. Spencer Jones[3] formed normal places from the Lick and the Cape observations, on which he based a least-squares solution for corrections to Merrill's elements. Merrill's and Jones's elements are given in the third and fourth columns of Table 1.

Few, if any other, observations appear to have been made until 1935. Then, at the request of Professor W. J. Luyten, three spectrograms were obtained on succeeding nights with the coudé spectrograph of the 100-inch reflector at Mount Wilson and sent to him for measurement without critical inspection.

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 605.

[1] *Ap. J.*, **10**, 241, 1899.

[2] *Lick Obs. Bull.*, **6**, 5, 1910.

[3] *Ann. Cape Obs.*, **10**, Part 8, 76, 1928.

The spectral region about the H and K lines of *Ca* II are well exposed upon all three plates. This part of the spectrum was not observed in the earlier work at the Lick and Cape observatories.

Luyten was interested in finding whether anything could be learned about the relative masses of the components of β Capricorni through the possible presence of the secondary's lines in the spectrum. The time chosen for observation corresponded to the maximum velocity difference for the component stars and hence to the widest separation of their respective spectral lines. The velocity of

TABLE 1

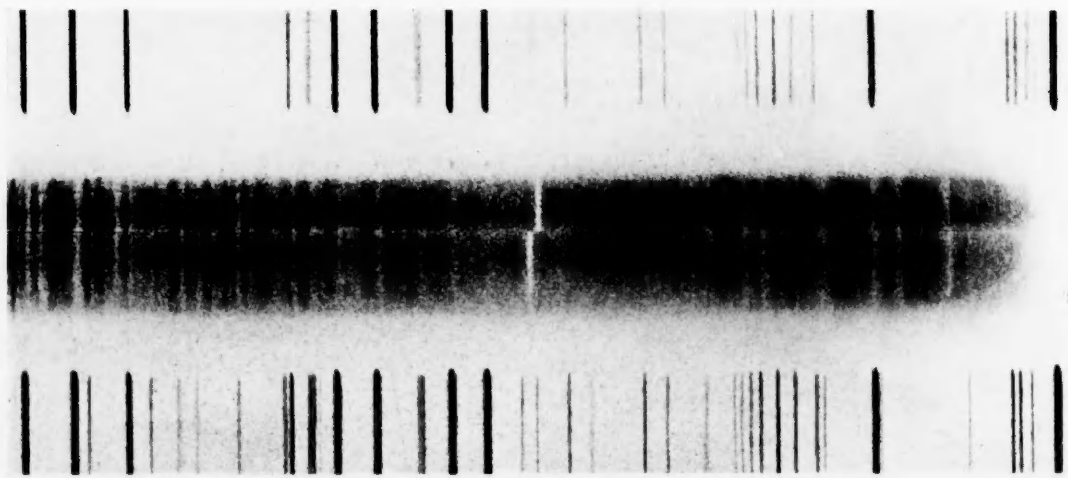
β CAPRICORNI—ORBITAL ELEMENTS OF STARS A AND (B+C)

ELEMENT	MERRILL	JONES	SANFORD	
	Star A	Star A	Star A	Stars (B+C)
P	$1375^{d}.3$	$1378^{d}.49 \pm 1^{d}.28$	$1374^{d}.126 \pm 2^{d}.06$	$1374^{d}.126$
T	JD 2416035	2416031.49 ±2.10	2421521.26 ±3.35	2421521.26
ω	124°	122.76 ±0°.92	119.12 ±1°.29	299°.12
e	0.44	0.437±0.06	0.417±0.06	0.417
K	22.2	22.44 ±0.19	21.93 ±0.22	20.00 km/sec
γ	−18.8	−19.02	−18.94	−18.94 km/sec
$a \sin i$	377,000,000	382,500,000	395,050,000	360,300,000 km
$m \sin i$	....	....	4.35 $\odot$	4.77 $\odot$

the primary agreed fairly well with prediction, but Luyten found no lines that could be ascribed to a secondary star having the same period as the primary. But the velocities derived from the *Ca* II lines H and K not only did not agree with the other lines but varied through a large range in the forty-eight hours covered by the three spectrograms. Plate XX reproduces this portion of the spectrum for the first and third of these three plates, which are adjusted to coincidence for the spectral lines of the primary. The manifest offset for the K line corresponds to 50 km/sec.

Luyten then returned the spectrograms and called attention to this interesting result. Then it was noticed that the region of H and K was not normal for the dominant spectrum. Wide and quite deep absorption should go with the Go spectrum, whereas these three plates, well exposed in this region, show a narrow, fairly sharp K line on a background nearly as strong as any of the contiguous continu-

PLATE XX



TWO SPECTROGRAMS OF β CAPRICORNI: UPPER, SEPTEMBER 8; LOWER, SEPTEMBER 10, 1935; ADJUSTED FOR COINCIDENCE OF THE LINE DETAIL OF STAR A

The strong K lines of calcium at the center belong to star B and are definitely out of step. The large shift to the violet in the lower spectrogram indicates that the velocity of approach of B exceeds by 50 km/sec that in the upper spectrogram.

ous spectrum and a similar H line in the violet wing of a broad absorption feature. This, of course, only added to the interest aroused by the rapid velocity change given by these lines. Observations covering the H and K region were undertaken at once in an effort to find the law of variation for the velocities from the *Ca* II lines.

Practically all the Mount Wilson observations may be placed in two groups, the V series having a dispersion of approximately 24 A/mm at H and K, and the coudé series with a dispersion of about 10 A/mm.

It was soon evident that the period was indeed short relative to the primary's period. This fact and the general appearance of the H and K region seemed most easily explained by assuming that the primary of class G0 has for a secondary in its long-period orbit not a single star but a close double. The brighter member of the double seems to be of class B8 and to furnish the *Ca* II lines which show the rapid velocity shifts. Before many spectrograms had been measured Dr. W. S. Adams found that *Si* II lines at λλ 3853, 3856, and 3862 are present and have the same velocity shifts as H and K.

One spectrogram of β Capricorni has been obtained with a quartz spectrograph at the coudé focus of the 100-inch reflector. In it the lines of the G0-type spectrum can still be well seen, though veiled, down to the limit at about λ 3200 A. This would indicate that the brightness of the B8 star cannot much exceed that of the G0 star even at this wave length. In the H and K region the B8 star would then probably be considerably fainter than the G0 star. This, in fact, appears to be the case; for a broad dip, corresponding to the K line of the G0 star, is easily seen if the adjacent continuous spectrum is not too strongly exposed. That the *Ca* II lines of the B8 star are still observable, although it is noticeably fainter than the G0 star, is due to the windows in the brighter star's spectrum provided by the broad H and K lines. Windows furnished by the band absorption of cyanogen explain the possibility of observing *Si* II. The other lines of the B8 star would then be masked by the continuous spectrum of the relatively bright G0 star, another fact of observation.

Observations were continued through the 1938 season. The spectrograms suitable for measurement are listed in the second group in Table 2, where the plate numbers serve to show which dispersion was

TABLE 2

RADIAL VELOCITIES OF β CAPRICORNI

Plate No.	JD (G.C.T.)	Phase	Star A		Star B from *Ca* II and *Si* II	
			Obs. Vel.*	O−C	Obs. Vel.	O−C
		days	km/sec	km/sec	km/sec	km/sec
....	2414518.3	1241.8	− 5.4	+0.9	....	....
....	4791.5	140.9	−43.4	+0.3	....	....
....	92.5	141.9	−45.9	−2.2	....	....
....	4805.5	154.9	−44.5	−1.5	....	....
....	15.5	164.9	−42.4	−0.1	....	....
....	21.5	170.9	−42.4	−0.5	....	....
....	33.4	182.8	−41.1	+0.7	....	....
....	49.4	198.8	−40.3	−0.3	....	....
....	61.4	210.8	−39.7	−0.6	....	....
....	80.3	229.7	−37.8	+0.2	....	....
....	83.3	232.7	−38.6	−1.0	....	....
....	4903.2	252.6	−35.2	+0.8	....	....
....	09.2	258.6	−34.5	+1.0	....	....
....	19.2	268.6	−35.1	−0.1	....	....
....	24.1	273.5	−33.0	+1.5	....	....
....	25.2	274.6	−33.8	+0.7	....	....
....	45.1	294.5	−31.8	+1.4	....	....
....	5155.5	504.9	−20.9	−0.1	....	....
....	5204.5	553.9	−16.7	+1.7	....	....
....	45.3	594.7	−16.2	+0.2	....	....
....	83.2	632.6	+13.6	+1.2	....	....
....	5317.2	666.6	+11.8	+1.6	....	....
....	5518.5	867.9	+ 6.1	+0.2	....	....
....	76.4	925.8	+ 5.6	−1.2	....	....
....	5618.3	967.7	+ 3.4	−0.4	....	....
....	73.2	1022.6	+ 2.7	−0.6	....	....
....	5896.5	1245.9	+ 7.4	+0.6	....	....
....	5909.5	1258.9	+ 8.9	+0.4	....	....
....	25.5	1274.9	+12.2	−0.4	....	....
....	39.4	1288.8	+14.5	−0.4	....	....
....	63.4	1312.8	+18.6	+0.2	....	....
....	75.3	1324.7	+20.4	+0.9	....	....
....	81.3	1330.7	+23.0	0.0	....	....
....	88.3	1337.7	+25.2	−0.2	....	....
....	6003.2	1352.6	+29.8	−1.0	....	....
....	23.2	1372.6	+33.7	+0.1	....	....
....	32.2	7.5	+36.2	−0.2	....	....
....	6332.3	307.6	+32.6	−0.3	....	....
....	51.3	326.6	+30.4	+0.6	....	....
....	79.2	354.5	+31.2	−1.9	....	....
....	6418.1	393.4	+25.8	+1.0	....	....
....	8221.8	822.9	− 7.4 C	+0.5	....	....
....	22.8	823.9	− 7.7 C	+0.2	....	....
....	24.8	825.9	− 8.5 C	−0.7	....	....
....	33.8	834.9	− 8.3 C	−0.8	....	....

* Velocities from the Cape Observatory are followed by the letter "C"; all others without plate numbers are from the Lick Observatory. The rest were obtained at Mount Wilson.

TABLE 2—*Continued*

Plate No.	JD (G.C.T.)	Phase	Star A Obs. Vel.	Star A O−C	Star B from *Ca* II and *Si* II Obs. Vel.	Star B O−C
		days	km/sec	km/sec	km/sec	km/sec
....	2418427.2	1028.3	− 2.4 C	−0.4	....	....
....	44.2	1045.3	− 2.1 C	−0.4	....	....
....	8532.3	1133.4	− 2.0	−0.5	....	....
....	53.9	1155.0	− 3.9 C	−1.9	....	....
....	57.4	1158.5	− 1.0 C	+1.0	....	....
....	64.2	1165.3	− 1.8	+0.5	....	....
....	75.9	1177.0	− 4.5 C	−1.7	....	....
....	8606.1	1207.2	− 4.1	+0.6	....	....
....	10.8	1211.9	− 3.1 C	+1.9	....	....
....	44.1	1245.2	− 7.0	+1.0	....	....
....	8959.8	186.8	−43.4 C	−2.4	....	....
....	66.8	193.8	−41.3 C	−0.8	....	....
....	9184.2	411.2	−25.2 C	+0.4	....	....
....	9205.2	432.2	−24.3 C	+0.2	....	....
....	9211.2	438.2	−25.6 C	−1.3	....	....
....	9313.8	540.8	−19.7 C	−0.7	....	....
....	9672.9	899.9	− 4.8 C	+0.2	....	....
γ 6056..	2421447.315	1300.2	−19.9	−3.5	....	....
γ 7291..	1854.256	333.0	−33.2	−2.5	....	....
Ce 954..	8055.155	1037.4	− 0.8	+1.1	− 6.5	− 2.2
Ce 957..	56.174	1038.4	+ 0.8	+2.7	−20.8	+12.0
Ce 961..	57.229	1039.5	− 3.7	−1.8	−56.6	− 8.0
V 1107..	64.121	1046.4	− 3.3	−1.7	−12.5	+ 1.3
Ce 1046	8299.458	1281.7	−11.9	+1.1	−26.9	+ 1.9
Ce 1051..	8300.475	1282.7	−10.8	+2.2	−36.2	+ 4.7
Ce 1057..	01.478	1283.7	−11.4	+1.9	−50.6	− 3.4
Ce 1059..	24.406	1306.6	−16.9	+1.0	− 1.4	− 3.6
Ce 1064..	25.458	1307.7	−18.7	−0.7	−24.9	− 1.1
Ce 1067..	54.420	1336.7	−24.3	+0.5	−37.4	+ 0.7
Ce 1073..	56.420	1338.7	−27.0	−2.0	−17.5	0.0
V 1444..	56.319	1338.6	−26.0	−1.0	−18.8	+ 1.7
V 1458..	79.239	1361.5	−30.0	+1.0	−31.8	− 3.5
V 1468..	80.328	1362.5	−27.7	+3.3	−35.7	− 4.4
V 1475..	81.414	1363.6	−32.6	−0.8	−23.8	+ 3.9
γ 21044..	83.278	1365.5	−28.9	+3.3	+19.6	− 0.4
Ce 1084..	84.254	1366.5	−34.0	−1.3	+45.5	+ 1.8
Ce 1089..	85.335	1367.6	−33.7	−0.8	+16.2	+ 4.4
Ce 1094..	86.352	1368.6	−30.6	−2.3	−14.8	− 3.5
Ce 1098..	87.410	1369.6	−35.0	−2.0	−19.6	+ 3.7
Ce 1102..	88.358	1370.6	−33.8	−0.5	−33.1	− 4.8
V 1505..	92.294	0.4	−36.2	−2.2	+33.0	− 3.9
V 1511..	93.314	1.4	−38.3	−4.3	+35.6	+ 0.6
Ce 1125..	8412.238	20.4	−39.0	0.0	− 1.6	+ 2.9
Ce 1128..	13.158	21.3	−40.0	−0.8	−13.0	+ 2.9
V 1522..	13.307	21.4	−39.4	−0.2	−12.7	+ 4.7
Ce 1133..	14.158	22.3	−33.6	+5.6	−21.2	+ 1.8
Ce 1141..	18.146	26.3	−42.9	−3.0	+33.4	0.0
V 1535..	18.212	26.3	−38.4	+1.6	+38.1	+ 1.8

TABLE 2—*Continued*

Plate No.	JD (G.C.T.)	Phase	Star A		Star B from *Ca* II and *Si* II	
			Obs. Vel.	O−C	Obs. Vel.	O−C
		days	km/sec	km/sec	km/sec	km/sec
Ce 1148..	2428419.309	27.4	−46.8	−6.8	+35.2	− 5.1
V 1554..	20.190	28.3	43.2	−3.0	+15.5	+ 2.1
Ce 1153..	41.179	49.3	44.3	−1.5	−20.5	+ 1.1
V 1598..	42.184	50.3	42.4	+0.7	−12.3	+ 5.4
V 1604..	43.126	51.2	46.6	−3.3	− 4.2	− 0.9
Ce 1168..	47.146	55.3	41.4	+2.2	+ 6.5	+ 9.5
Ce 1173..	48.151	56.3	42.2	+1.5	−14.1	+ 0.1
V 1631..	70.125	78.2	45.6	−0.6	+35.4	+ 1.5
V 1645..	78.125	86.2	50.2	−5.0	+ 1.6	− 5.9
V 1674..	8504.082	112.2	47.4	−2.2	− 9.4	−14.1
V 1675..	05.086	113.2	46.9	−1.9	+44.8	− 0.6
V 1863..	8655.491	263.6	33.8	+1.5	−13.3	− 1.8
V 1864..	55.511	264.6	32.5	+2.7	−16.4	− 4.6
Ce 1366..	78.491	286.5	35.6	−2.0	+24.9	− 3.7
Ce 1369..	79.493	287.6	32.4	+1.1	+38.9	− 1.3
V 1886..	81.488	289.6	30.5	+2.9	−17.2	− 4.7
V 1902..	8705.417	313.5	32.0	−0.1	+36.8	− 4.4
Ce 1385..	07.488	315.6	32.0	−0.3	−12.0	+ 1.7
Ce 1388..	08.474	316.6	30.3	+1.3	−24.1	+ 0.7
Ce 1393..	09.490	317.6	31.6	0.0	−34.0	− 3.7
Ce 1428..	44.283	352.4	29.7	−0.3	−33.6	− 5.3
V 1970..	46.303	354.4	30.5	−1.2	−27.2	− 1.2
Ce 1451..	71.276	379.4	27.1	+0.8	−37.2	− 2.2
Ce 1457..	72.199	380.3	30.4	−2.7	−27.2	+ 1.9
Ce 1464..	73.272	381.4	30.6	−3.0	−15.6	−10.5
V 1997..	74.312	382.4	....	....	+33.6	− 3.3
V 2001..	75.285	383.4	25.6	+1.9	+21.4	− 2.4
Ce 1496..	8804.118	412.2	27.2	−1.6	−27.0	+ 5.0
Ce 1532..	30.125	438.2	25.3	−1.0	−37.8	− 4.5
V 2078..	32.106	440.2	....	....	−32.2	+ 6.1
V 2085..	33.101	441.2	20.8	+3.2	−30.3	+ 0.3
V 2091..	34.099	442.2	21.9	+2.1	− 6.6	− 0.7
Ce 1563..	60.119	468.2	20.7	+2.0	− 8.4	− 0.7
Ce 1687..	9040.474	648.6	13.6	+0.6	−38.4	+ 8.7
Ce 1690..	63.483	671.6	13.5	−0.3	−32.9	+ 0.6
Ce 1707..	66.483	674.6	14.2	−1.0	−44.3	+ 3.6
Ce 1738..	77.490	685.6	12.6	0.0	− 1.6	− 2.2
V 2335..	93.308	701.4	14.2	−2.0	−42.5	+ 0.7
V 2381..	9128.172	736.3	16.6	−5.7	−36.0	+ 6.3
γ 21385..	52.120	760.2	12.0	−1.8	−50.6	+ 0.1
Ce 1786..	53.122	761.2	10.2	−0.2	−53.6	− 2.1
Ce 1799..	9181.149	789.2	−10.7	−1.6	−30.0	− 8.0

used. The first group includes the Lick and the Cape (C) Observatory velocities.

The interval between the first and last observations of Table 2 is

forty years and covers more than ten revolutions of the primary. The complete data should therefore furnish a far more accurate period than could be found when the observations covered but fourteen years. In fact, it seemed worth while to attempt the correction by least-squares of all of Merrill's elements for the primary.

It was convenient and quite admissible to form normal places from the individual velocities of the primary given in the fourth column of Table 2, keeping the three series separate, however. These normals—10, 7, and 14 for the Lick, Cape, and Mount Wilson observatories, respectively—are in Table 3. The number of plates in each normal varies widely because it was deemed best to combine into a single normal only those covering a comparatively short phase interval and not widely separated in the time of observation. The normal places were compared with velocities derived from a set of preliminary elements. The new observations seemed to indicate a period definitely shorter than Merrill's instead of longer, as found by Jones. Except for fairly obvious changes in P and T, Merrill's elements were therefore chosen as preliminary values. The revised elements from this solution are given in the fifth column of Table 1. The corresponding value of Σpv^2 is 62 per cent of that from the preliminary elements used.

The three sets of elements given in Table 1 do not differ significantly except for the period P. Jones's solution increased Merrill's value by 3.19 days, whereas the present discussion decreases it 1.17 days. The data now available, however, extend over a much larger number of revolutions; and, what is even more important for the determination of the period, the steep descending branch of the velocity-curve is well covered at two widely separated epochs. At the same time, a comparison of the residuals in the fifth column of Table 2 with Jones's values shows that the representation of the Cape and the Lick observations has not suffered by the revision.

As observations accumulated, it became evident that the velocities derived from the *Si* II and *Ca* II lines varied in a period of something over eight days. The value finally determined from the Mount Wilson observations covering approximately 170 periods was 8.6780 days. Although the form of the short-period variation appeared to remain constant, it was soon found that the mean velocity about

TABLE 3

β CAPRICORNI—NORMAL PLACES FOR STAR A

Phase (Days)	No. of Plates*	Velocity (Km/Sec)	O−C (Km/Sec)
	Lick		
182.8	10	−41.8	−0.2
300.0	10	32.4	+0.6
590.5	5	15.8	+1.0
946.0	4	4.5	−0.5
1249.2	3	7.2	+0.8
1292.1	3	15.1	−0.5
1331.0	3	22.9	+0.4
1368.9	3	33.2	−0.4
1149.4	2	1.9	0.0
1226.2	2	− 5.5	+0.2
	Cape		
826.9	4	− 8.0	−0.3
1036.8	2	2.3	−0.2
1175.7	4	3.1	−0.4
190.3	2	42.4	−1.5
427.2	3	25.0	0.0
540.8	1	19.7	−0.6
899.9	1	− 4.8	+0.5
	Mount Wilson		
1038.4	3 Ce	− 1.2	+0.9
1292.5	5 Ce	13.9	+0.8
1357.2	5 V	31.9	−1.9
1359.8	7 Ce	31.2	−0.7
15.6	5 V	39.1	−1.6
22.5	4 Ce	37.0	+1.8
53.6	3 Ce	42.6	+0.7
81.9	6 V	46.5	−1.4
304.8	5 Ce	32.4	+0.2
344.0	8 V	28.4	+1.6
373.4	4 Ce	29.6	−1.5
439.6	3 Ce	24.4	−0.1
670.1	4 Ce	13.5	−0.1
701.4	1 V	14.2	−1.9
761.2	1 Ce	−10.2	−0.2

* V following the number indicates that all plates in the normal are of the V series; Ce, that all are coudé plates.

which the curve oscillated simulates that of a secondary to the primary star having a period of 1374 days. In other words, β Capricorni is a system comprised of the three stars, A, B, and C. A and (B + C) are the primary and the secondary of the long-period binary; B and C, the brighter and the fainter stars of the short-period binary. Only the G0 type of star A and the B8 spectrum of star B can be observed.

A velocity-curve for the center of mass of (B + C) could be obtained from the velocities based upon *Si* II and *Ca* II if B's velocity-

TABLE 4

β CAPRICORNI—NORMAL PLACES FOR (B+C) FROM COUDÉ SPECTROGRAMS

Phase	Velocity	O−C
days	km/sec	km/sec
1038.4	−34.0	+0.5
1282.7	−23.3	+1.1
1307.2	−23.0	−3.0
1337.6	−16.6	−3.2
1368.6	− 3.3	+2.2
23.3	+ 1.3	+1.8
53.6	+ 6.4	+2.8
312.7	− 9.2	−2.4
409.3	−14.3	−2.0
671.1	−22.2	+1.8
718.8	−26.9	−1.3

curve about the zero axis were known. The approximate shape of the short-period curve was determined from the observations of August, 1936, and used to find rough values for the velocity of (B + C). With these the velocity-curve of (B + C) could be approximated. This curve then permitted the derivation of velocities for B about the zero axis for all the spectrograms measured and hence of an improved velocity-curve for B. Successive repetitions of this process soon led to values which showed no further significant change.

At this stage normal places were derived for the velocities of (B + C) based only on results from coudé plates (Table 4). The elements P, T, ω, e, and γ are better determined from star A. The semiamplitude of velocity variation, K_{B+C}, was, however, found by a least-squares solution to be 20.00 km/sec.

The normal places for A and (B + C) from Tables 3 and 4 are plotted in Figure 1, together with the curves corresponding to the adopted elements in Table 1. The residuals appearing in Tables 3 and 4 were scaled from the figure.

The individual velocities of B, freed from the center-of-mass velocities of (B + C), were examined next to be sure that they showed no change with phase in the long-period orbit. Since the observations cover many revolutions in the short-period orbit, the period 8.6780 days could be assumed to be accurate. The individual observations were therefore grouped into normal places strictly by

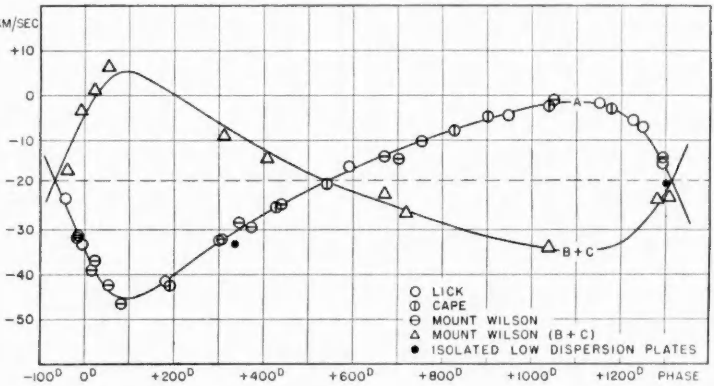


FIG. 1.—Radial-velocity curves of A and the center of mass of (B + C)

phase intervals within which velocity changes were closely linear (Table 5 and Fig. 2).

A free-hand curve through the plotted points was used for a graphical determination of the elements of B's orbit. Since the data depend on an approximation process, there seems little justification for a least-squares adjustment of these elements. The preliminary values were modified largely by cut and try methods until the normal places of Table 5 were reasonably well represented. The adopted elements in Table 6 are the basis of the velocity-curve in Figure 2.

Table 1 contains the elements for star A and the center of mass of (B + C); and Table 6, those for star B. Figure 1 is based upon the former, and Figure 2 upon the latter. The residuals for the primary given in Table 2 have been obtained by comparing the observed

velocities with values scaled from the velocity-curve of A. As already mentioned, the representation of the Lick and Cape observations compares favorably with that obtained by Jones. The Mount Wilson observations, however, are not in agreement with Jones's elements.

TABLE 5

β CAPRICORNI—NORMAL PLACES FOR STAR B ABOUT ZERO AXIS

Phase	No. of Plates*	Velocity	O−C
days		km/sec	km/sec
+5.370	2 V	−22.8	+2.1
+5.638	7 Ce	−21.9	+2.4
+6.516	5 V	−15.4	+2.3
+7.146	2 V	− 6.6	+0.4
−1.215	3 Ce	− 0.6	−2.3
−1.197	3 V	− 3.4	−5.9
−0.622	2 V	+30.7	+5.2
−0.522	3 Ce	+28.7	−1.3
−0.269	4 V	+39.9	−1.6
+0.435	1 V	+43.3	−4.7
+0.450	2 Ce	+48.2	+0.7
+0.699	1 Ce	+35.1	−5.7
+0.808	2 V	+36.0	−1.0
+1.237	3 Ce	+23.1	+0.4
+1.444	2 V	+18.7	+2.4
+2.392	8 Ce	− 1.8	+3.2
+2.572	3 V	−11.4	−3.7
+3.292	4 Ce	−15.9	+0.1
+3.588	5 Ce	−18.8	+0.2
+3.665	3 V	−19.2	+0.4
+4.388	4 Ce	−25.4	−1.7
+4.568	1 V	−23.4	+1.1

* V following the number indicates that all plates in the normal are of the V series; Ce, that all are coudé plates.

The velocities obtained from *Ca* II and *Si* II appear in the sixth column of Table 2 and are assumed to be a composite of the velocities of B about the center of mass of (B + C) and of the center-of-mass velocity of (B + C). The residuals corresponding to this assumption are in the last column of the table. Four plates—V 1674, Ce 957, 1464, and 1687—give large residuals. Remeasurement confirmed the original velocities. Since for the V series the dispersion is moderate and the velocity usually depends largely upon the K line alone, the residual for V 1674 need cause no concern. The coudé spectrograms,

on the other hand, have a much larger dispersion and furnish from two to five lines for measurement. There is no evidence of systematic errors in the three plates in question, since the velocities for star A give normal residuals. Such residuals are to be regretted but

TABLE 6

β CAPRICORNI—ORBITAL ELEMENTS OF STAR B

Period (P)	8.6780	days
Periastron passage (T)	JD 2428383.898	G.C.T.
Angle periastron (ω)	343°24	
Eccentricity (e)	0.36	
Semiamplitude of velocity variation (K)	37.9	km/sec
Velocity of system (γ)	0.0	km/sec
$a \sin i$	4,226,000	km
$\dfrac{m_C^3 \sin^3 i}{(m_B + m_C)^2}$	0.040	⊙

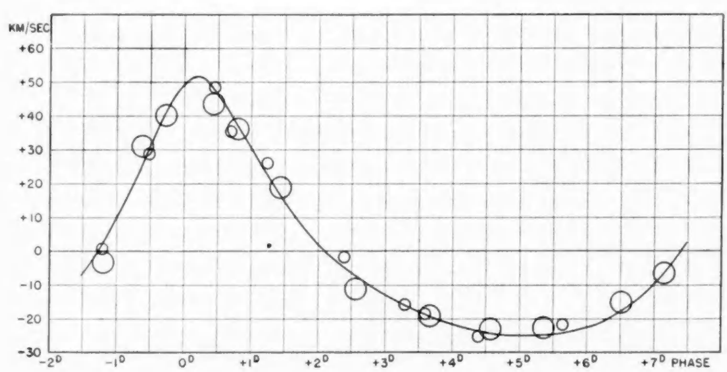


FIG. 2.—Radial-velocity curve of star B referred to zero axis. The plotted normal places have been formed from the velocities of star B based upon the *Ca* II and *Si* II lines, after the effect of the velocity variation of the center of mass of (B + C) has been eliminated from these measures. The less accurate normals from the V-series are the larger plotted circles.

are possibly no larger than occasionally to be expected in velocities based in no case on more than five lines.

An approximation for the relative magnitudes of the stars involved in this triple system might possibly be obtained from a photometric treatment of the spectrum. But the assumptions in-

volved are so uncertain that the matter has not been attempted even qualitatively. As already mentioned, it seems certain that in the H and K region star B must be considerably fainter than star A. Also, C must be fainter than B, since on none of the plates are the *Ca* II and *Si* II lines double, as would occasionally be the case if C were comparable in brightness with B. If C approximated B in magnitude but was later in spectral type, it would certainly produce effects upon the integrated spectrum that are not observed, e.g., provide broad absorption at K which, combining with that for star A, would reduce the continuous spectrum much more than is observed.

The smallest masses permitted by the adopted elements, corresponding to $i = 90°$ for both orbits, are 4.4, 3.9, and 0.9 $\odot$ for A, B, and C, respectively. The mass-luminosity law gives as corresponding absolute magnitudes -0.4, $+0.3$, and $+5.0$. The value for A (-0.4) is not far from the mean of that found spectroscopically ($+2$) and that obtained from the mean trigonometric parallax (-2.4). Moreover, these three values agree with the magnitude-spectrum diagram, provided A is a G0 giant, B a normal B8 star, and C a main-sequence star of about spectral class G5. For values of i less than 90° the masses will be larger, the absolute magnitudes from the mass-luminosity law will increase, conforming more nearly with the trigonometric parallax, and the fit with the magnitude-spectrum diagram will be less satisfactory. These considerations, together with the fact that the relative intensities of the spectra of A, B, and C are not at variance with the relations of the absolute magnitudes -0.4, $+0.3$, and 5.0, are evidence of some merit that i does not differ greatly from 90°.

It follows simply from the orbital dimensions and probable diameters of the stars that a very small departure of i from 90° is sufficient to prevent an eclipse of A by the other stars. A partial eclipse of B by C, and vice versa, is still possible with a considerably greater departure of its i from 90°. But to be detected from its effect on the integrated light of A, B, and C, the eclipse would require that a large percentage of B or C be covered; in other words, it would also require values of i close to 90°. Considerations of mass, luminosity, and spectrum have indicated that i is probably not far from 90°. The

dimensions of the orbits and probable diameters of the stars point to the possibility of detectable variation in the integrated light of β Capricorni only in case i is very close to 90° for both long- and short-period orbits. No variation of light is known. The elements which have been obtained should serve to indicate the best times of observation for effects of eclipse.

I am greatly indebted to Messrs. W. S. Adams and O. C. Wilson for many of the spectrograms listed in Table 2.

CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
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THE SPECTRA OF BRIGHT CHROMOSPHERIC ERUPTIONS FROM λ 3300 TO λ 11500*

R. S. RICHARDSON AND R. MINKOWSKI

ABSTRACT

Photographs of five chromospheric eruptions of intensity 2 and 3 were obtained with a concave-grating spectrograph including an all-mirror optical system. The spectral regions covered were λλ 3300–4000, 3900–6900, 8000–8900, and 10000–11500. The following lines showed emission over bright eruptions on the disk: λ 10830 of *He*, the infrared triplet of *Ca* II, the Balmer series from *Hα* to *Hι*, and λλ 3968.494, 3933.684, 3736.919 of *Ca* II. Bright eruptions at the limb, in addition to the lines above, showed λλ 10938.12 and 10049.39 of *H*; λλ 6678.149, 5875.79, and 4471.48 of *He*. No emission was observed at the limit of the Balmer series. There was no evidence that black-body radiation is associated with the bright eruptions.

It is pointed out that λ 584 of *He* may be of importance in producing variations in ionization at high levels in the ionosphere.

The first description of what is now generally known as a bright chromospheric eruption was made independently by Carrington[1] and by Hodgson[2] on September 1, 1859. This eruption has the distinction of being not only the first on record but also the brightest ever observed. Carrington's account is especially interesting, for it is typical of the experience of many observers on seeing one of these spectacular outbursts for the first time.

He was engaged in making his daily drawing of the sunspots when two patches of intensely bright white light suddenly broke out in the region of a large spot-group. At first he thought that a ray had penetrated the screen used to shade the image from diffuse light. But, on moving the image in right ascension, the bright spots moved along with it, convincing him at once that they were a solar phenomenon of an entirely new type. He noted the time, and then, thinking that it might be advisable to have someone to corroborate his story later on, rushed out of the room in search of a witness. Returning a minute later, he was much chagrined to find that the outburst was fading rapidly. A few minutes later it had vanished entirely, and, although he kept a close watch for an hour, there was no

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 606.

[1] *M.N.*, **20**, 13, 1859. [2] *Ibid.*, p. 15.

further activity. Fortunately, Hodgson also happened to be observing the sun at the same time, and his account agrees closely with that of Carrington. Since then many eruptions, evidently of the same kind, have been observed, but always as emission within some absorption line, usually $H\alpha$. The eruption of September 1, 1859, is the only one that became bright enough to be visible in integrated sunlight.

In 1931 Hale[3] summarized some remarkable eruptions that had been well observed and discussed their possible connection with terrestrial magnetic storms and auroras. The material was so scanty, however, that general conclusions were difficult—a circumstance not surprising in view of the scarcity of eruptions of exceptional brilliance, their short lifetime, and, above all, the total lack of any systematic effort to detect them.

This situation was decidedly altered in 1928 when Hale[4] finally succeeded in constructing a practical spectrohelioscope based on principles that had been well understood for over fifty years. Since with this instrument it is possible to see a large part of the solar disk much as it appears on a hydrogen spectroheliogram, any unusual activity is easily observed. By 1931 twenty-five coelostats and spectrohelioscopes had been distributed to stations all around the world and a co-operative plan adopted whereby the sun could be kept under continual observation. Anyone witnessing an eruption notes the time when it is first and last seen and its position, and estimates its intensity on a scale of 1 to 3. These records are sent to Zurich, which acts as a clearing house and publishes quarterly a complete report, together with several other indices of solar activity.

This program was started with no very definite object in mind other than to obtain better data for testing possible solar and terrestrial relationships. In 1935 a new incentive was given to workers in this field when J. H. Dellinger[5] called attention to a series of sudden and widespread fade-outs of high-frequency wireless transmission over the daylight side of the earth, and suggested that they might be connected with the bright eruptions described in Hale's paper. This idea was partially confirmed when by a fortunate coincidence it was

[3] *Mt. W. Contr.*, No. 425; *Ap. J.*, **73**, 379, 1931.

[4] *Proc. Nat. Acad.*, **10**, 361, 1924.

[5] *Phys. Rev.*, **48**, 705, 1935.

found that several spectroheliograms had been taken while the fade-outs were in progress and that eruptions had actually occurred at these times. The prospect of establishing a new solar and terrestrial relationship now seemed so promising that special observations were made at Mount Wilson for this purpose. Although some results generally favorable to this view were obtained,[6] a positive answer was not forthcoming until April 8, 1936. On that date an eruption of exceptional brilliance was observed both at the Carnegie Institution's magnetic observatory at Huancayo, Peru,[7] and at Mount Wilson.[8] Simultaneously, the instruments at Huancayo recorded a fade-out of ionosphere echoes and sudden disturbances in earth currents and the earth's magnetic field. The probability that four phenomena of such an unusual and definite character should all occur at once is practically negligible. In this single case, at least, it could be confidently asserted that a particular event on the sun had produced certain particular effects on the earth, and that the energy had been transmitted with the velocity of light.

This immediately stimulated research in a branch of astrophysics that previously had been somewhat neglected. Both the solar outbursts and their terrestrial effects have now been discussed in considerable detail. Enough data have accumulated to enable investigators in England,[9] Australia,[10] France,[11] Germany,[12] and the United States[13] to come to an agreement on the reality of the effect—a remarkable result in itself.

The most important terrestrial effects are the fade-outs in short-wave wireless signals on the daylight side of the earth and a sudden change of the magnetic elements in the same sense as the diurnal variation. It should be emphasized that the magnetic disturbance is of a type previously unrecognized[14] and must not be confused with a magnetic storm, which it does not resemble in any way. The fade-outs are attributed to an increase of ionization in the lowest level of

[6] *Pub. A.S.P.*, **47**, 325, 1935.

[7] *Terr. Mag.*, **41**, 199, 1936.

[8] *Pub. A.S.P.*, **48**, 178, 1936; *Terr. Mag.*, **41**, 197, 1936.

[9] *M.N.*, **97**, 594, 1937.

[10] *Nature*, **140**, 603, 1937.

[11] *La Météorologie*, January–February, 1938.

[12] *Zs. f. Ap.*, **14**, 229, 1937.

[13] *Terr. Mag.*, **42**, 49, 1937.

[14] *Phys. Rev.*, **52**, 155, 1937.

the ionosphere, called the D layer, at an elevation of only about 100 km. These effects are readily explained on the assumption of an intense burst of ultraviolet light from the eruptive flocculi, capable of penetrating the earth's atmosphere to the D layer and temporarily producing a high degree of ionization.[15] On this basis the emission most commonly observed in $H\alpha$ is regarded as being of minor importance, the really effective radiation coming from the unobservable ultraviolet part of the spectrum.

This hypothesis can best be tested by studying the spectra of the bright eruptions. The results obtained from photographs of bright eruptions taken from July 1 to December 10, 1938, follow.

APPARATUS AND METHOD OF OBSERVATION

The photographs were taken with a concave-grating spectrograph adjusted so that the second order was in focus from λ 3900 to λ 7000, giving a dispersion of 8.8 A/mm. Light from the coelostat and flat at the top of the 60-foot tower telescope was reflected in succession from a concave off-axis mirror, a convex, and a flat to form, finally, a 7-inch solar image on the slit. The mirrors are all aluminium coated. A spectrohelioscope was installed a few feet from the spectrograph, so that the beam from the coelostat could be swung quickly from one to the other. The disk was scanned almost continuously with the spectrohelioscope. When an eruption occurred, its position was identified, and it was then brought onto the slit of the spectrograph as closely as possible. The bright flocculi were then examined in detail with an eyepiece inserted in the spectrograph at the position of $H\beta$ in the third order. The brightest part was then centered on the slit by means of the guiding eyepiece and the slow motions that control the coelostat and flat. The exposures were made, while guiding with the eyepiece, simply by operating a shutter.

The ultraviolet and visual regions were photographed on 35-mm motion-picture film, stretched along the focal curve between two spools, each capable of holding 100 feet of film. After an exposure the correct length of film could be wound up for the next one by

[15] *Nature*, **140**, 603, 1937.

watching a counter on the side of the magazine that held the film. Since the exposures were only a few seconds long, a large number could be taken during an eruption. In the infrared, short strips of glass plate had to be used instead of film, which made it necessary to reload the magazine in the darkroom.

The region $\lambda\lambda$ 3300–4000 was photographed in the third order on positive film through a UG-2 filter; $\lambda\lambda$ 3900–6900 was secured in the second order on II-F emulsion. To photograph the region $\lambda\lambda$ 8000–8900 in the first order, 144-P plates were used directly without ammoniating. The Eastman I-Z emulsion sensitized with ammonia was used to photograph the interval $\lambda\lambda$ 10000–11500. The infrared was photographed through a λ 6300 filter.

Exceptionally bright eruptions are rather difficult to photograph, owing to their scarcity, their short lifetime, and the fact that they appear suddenly without any previous warning. The observer is in a position somewhat similar to that of a man trying to photograph the corona without knowing when an eclipse will occur. He must watch continuously and keep his instruments always in readiness for the moment when they will suddenly be needed.

Since the observations were made shortly after sunspot maximum, spots were exceptionally plentiful. Hardly a day passed without seeing two or three eruptions of intensity <1, evidence that they are not an especially rare solar phenomenon. But while small outbursts are fairly common, a really bright eruption is a rare event, only five being observed that were called 2 and 3.

In the beginning, it was hoped to obtain accurate intensities of the emission in different lines; but difficulties in developing the film uniformly and in eliminating scattered light in the spectrograph turned out to be greater than anticipated. In consequence, this part of the program had to be abandoned. The intensities in Table 1 are therefore only eye-estimates, and somewhat uncertain owing to photometric errors. In addition, since the whole spectral region could not be photographed at once, the intensities are from exposures made at different stages of the development of an eruption and also on different eruptions. But since the range of intensity among the different lines is small, it is believed that the estimates are fairly trustworthy. They are a combination of the total area of the emis-

sion and its brightness in terms of the neighboring continuous spectrum.

There appears to be no essential difference in the spectral characteristics of the eruptions; that is, an eruption of intensity 3 differs from one of intensity 1 only in brightness. In eruptions of intensity 2 and 3, the emission in $H\alpha$ is generally at least as bright as that of the continuous spectrum nearby.

TABLE 1

LINES AFFECTED IN BRIGHT CHROMOSPHERIC ERUPTIONS

λ_{IA}	IDENT.	INTENSITY		LOWER EP
		Disk	Chrom.	
10938.12	*H*	. . . .	10	12.04
10829.7	*He*	25	30	19.74
10049.39	*H*	. . . .	7	12.04
8662.17	*Ca* II	7	4	1.685
8542.13	*Ca* II	10	7	1.693
8498.06	*Ca* II	5	0	1.685
6678.149	*He*	. . . .	10	21.13
6562.816	$H\alpha$	50	100	10.16
5875.79	*He* (D3)	. . . .	15	20.87
4861.344	$H\beta$	40	30	10.16
4471.48	*He*	. . . .	5	20.87
4340.477	$H\gamma$	30	15	10.16
4101.750	$H\delta$	25	10	10.16
3970.078	$H\epsilon$	30	10	10.16
3968.494	*Ca* II (H)	70	25	0.000
3933.684	*Ca* II (K)	100	30	0.000
3889.052	$H\zeta$	20	8	10.16
3835.387	$H\eta$	15	. . . .	10.16
3797.900	$H\theta$	10	. . . .	10.16
3770.63	$H\iota$	5	. . . .	10.16
3736.919	*Ca* II	5	. . . .	3.137

Helium.—Undoubtedly the most interesting result is the appearance of the helium line at λ 10830 in emission over an eruption of intensity 3 that occurred near the center of the disk, on December 7, 1938. This is the only line showing in emission on the disk, with no absorption. This line is also conspicuous in a photograph of a bright eruptive prominence on the limb, but this was to have been expected. The helium lines at $\lambda\lambda$ 6678, 5876, and 4471 appeared in a bright eruption that was caught on the limb, but there is no trace

of them on the disk. The Fraunhofer D3 line, λ 5876, frequently shows as a faint absorption line over spot-groups, but it could not be discerned on any of the photographs taken in this work. There was no indication of λ 4686 of *He* II, although a careful search was made for it.

Hydrogen.—The bright emission is a notable feature in the Balmer series. No continuous emission was seen at the limit of the series, but the multiplicity of lines in this part of the solar spectrum might easily have obscured it. If present at all, it must be very weak.

No trace of emission could be seen in the Paschen lines at λ 10938 and λ 10049 in an eruption on the disk, although on the same plate λ 10830 of *He* was easily seen, and $H\delta$ in the third order showed emission brighter than the continuous spectrum. Plate stains from the ammoniating bath make it impossible to say that there is no emission at all in these lines; but it can be definitely stated that if present it must be very weak, even in an eruption of intensity 3.

Ionized calcium.—The infrared triplet and H and K show in emission on the disk, even in small eruptions. Emission was also detected with certainty in λ 3737, but its companion at λ 3706 could not be found.

The continuous spectrum.—None of the photographs shows any emission throughout the continuous spectrum over the eruptive flocculi. A bright streak appears in the visual region (no exposures were made in the ultraviolet), on photographs of the eruption of December 7, 1938, but *not* at the position of the line emission.

The investigation gives no evidence that black-body radiation, of either quality or quantity sufficient to account for the observed terrestrial effects, is associated with the bright chromospheric eruptions.

DISCUSSION

It is not intended to attempt here a detailed discussion of the questions which are raised by the occurrence of changes of ionization in the earth's atmosphere simultaneously with the appearance of bright eruptions. It should be emphasized, however, that the presence of helium lines in the spectra of bright eruptions is not without significance for the problem of the atmospheric ionization.

So long as only hydrogen lines had been observed in the spectra of bright eruptions, *Lyα* was the only radiation in the far ultraviolet whose presence was indicated by observational evidence. It is indeed to be expected that virtually every transition leading to the emission of *Hα* is immediately followed by a transition leading to the emission of *Lyα*, since the lower level of *Hα* is the upper level of *Lyα*, which has a high transition probability. While *Lyα* is not capable of directly ionizing oxygen and nitrogen, processes are known by which absorption of *Lyα* may affect the ionization in the atmosphere. Thus, as has been discussed by Martyn, Munro, Higgs, and Williams,[16] absorption of *Lyα* in the earth's atmosphere may explain to a great extent, if not completely, the changes of atmospheric ionization which lead to the radio fade-outs.

But, just as the emission of *Hα* is followed by the emission of *Lyα*, the emission of helium λ 6678 ($2^1P - 3^1D$) will be succeeded by that of λ 584 ($1^1S - 2^1P$). The latter line is capable of ionizing directly all constituents of the earth's atmosphere with the exception of helium. Radiation of this wave length is absorbed strongly in the atmosphere. It is therefore not to be expected that absorption of λ 584 plays a role in the changes of ionization in the D region, which are mainly responsible for the fade-outs. The effects produced by λ 584 may be of importance, however, for those variations of the ionization in higher regions which accompany the fade-outs.

The question whether λ 6678, and by inference λ 584, is a regular feature of the spectrum of bright eruptions deserves some discussion. The line was observed only at the limb and could not be seen on the disk. The presence of λ 10830 ($2^3S - 2^3P$) on the disk gives no indication of the intensity of λ 6678, since the relative intensities of the singlet and triplet lines of *He* are subject to pronounced variations depending on the conditions of excitation. However, in view of the fact that the lines λ 5876 ($2^3P - 3^3D$) and λ 4472 ($2^3P - 4^3D$) were also not to be seen on the disk, it seems reasonable to assume that the intensity of these lines and of λ 6678 is merely insufficient to allow their perception on the background of the continuous spectrum of the disk. The line λ 10830, one of the very strongest

[16] *Ibid.*

in the spectrum of *He*, may show easily at the same time with considerable intensity. This conception is supported by the fact that the hydrogen lines of the Paschen series, λ 10938 and λ 10049, are also visible at the limb, but not on the disk. The upper levels of these lines are at the same time the upper levels of $H\delta$ and $H\epsilon$, respectively; the intensity ratios $10938/H\delta$ and $10049/H\epsilon$ should therefore not be subjected to pronounced variations. Further observations are desirable, however, before definite conclusions can be drawn on the intensity of helium lines in the spectra of bright eruptions.

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ROTATION EFFECTS, INTERSTELLAR ABSORPTION AND CERTAIN DYNAMICAL CONSTANTS OF THE GALAXY DETERMINED FROM CEPHEID VARIABLES*

ALFRED H. JOY

ABSTRACT

Data.—The radial velocities of 156 variable stars of the δ Cephei type are available for a determination of the rotation of the galaxy, the coefficient of interstellar absorption, and certain galactic constants.

Distribution.—The δ Cepheids are situated close to the plane of the galaxy and, as seen from the earth, they are well distributed in longitude. The known stars of this type are considerably clustered about the sun.

Interstellar absorption.—The distances used are determined from apparent magnitudes and absolute magnitudes derived from the period-luminosity curve. In order that the rotation effect may show a linear relationship with distance, it is found necessary to correct the distances by postulating the presence of interstellar absorption. The coefficient of absorption is estimated to be 0.85 mag/kpc and the absorbing material is assumed to be uniformly distributed about the galactic plane in a layer having a total thickness of 0.4 kpc.

Rotational effects and galactic constants.—For a study of galactic rotation the stars are divided into four distance groups. Solutions by Oort's method give for l_0, the longitude of the direction to the center of rotation, $325^\circ.3 \pm 1^\circ.3$, and for A, the rotation effect at one kiloparsec, 20.9 ± 0.8 km/sec. The distance to the center is estimated to be 10 kpc. By the use of Bottlinger's formula the circular orbital velocity of the sun is found to be 296 km/sec and the period 207,000,000 years.

Residual radial velocities.—After taking out the effect of a solar motion of 20 km/sec and circular rotational effects, the average residual radial velocity is 10.8 km/sec.

In *Mount Wilson Contribution* No. 578 the data concerning the period, magnitude, and radial velocity of 155 stars of the δ Cephei type are compiled. The periods range from 1.5 to 45.2 days. One star, V 383 Cygni, the normal velocity of which is -20.0 km/sec, has since been added to the list. On account of their great distance, small peculiar motion, and concentration toward the plane of the galaxy, the effect of galactic rotation should be especially well shown by these stars.

I. THE DATA

In Table 1 the observational data necessary for the study of galactic rotation are listed. The third and fourth columns give the galactic co-ordinates as read from Ohlsson's tables,[1] which are based

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington,* No. 607.

[1] *Lund Obs. Ann.*, No. 3, 1932.

TABLE 1

DATA PERTAINING TO GALACTIC ROTATION OF CEPHEID VARIABLES

Star	log Period	l	b	Median m_{pg}	M_{pg}	Photometric Distance	Corrected Distance	Normal Velocity	V'
						kpc	kpc	km/sec	km/sec
V336 Aql	0.86	1°9	−3°6	10.8	−1.6	3.02	1.61	+11.5	+28.7
SZ Aql	1.23	3.3	−3.8	10.4	2.3	3.47	1.75	+9.5	+26.8
TT Aql	1.14	3.7	−4.6	8.3	2.1	1.20	0.86	0.0	+17.2
FN Aql	0.98	6.3	−4.4	10.4	1.8	2.75	1.52	+8.0	+25.6
BH Oph	1.04	7.5	+11.9	13.0	2.0	10.00	9.55*	+33.0	+52.2
η Aql	0.86	8.8	−14.5	5.0	1.6	0.21	0.19	−15.1	+0.9
BB Her	0.88	11.0	+5.4	10.1	1.7	2.29	1.35	+91.0	+109.9
FM Aql	0.79	12.0	−0.5	9.6	1.5	1.66	1.08	−12.0	+6.4
BL Her	0.62	12.6	+18.2	10.6	1.3	2.40	2.22*	+14.5	+34.3
AP Her	1.02	14.7	+6.1	10.6	1.9	3.16	1.65	−29.5	−10.4
FF Aql	0.65	16.8	+5.1	6.0	1.3	0.29	0.26	−14.4	+4.7
KL Aql	0.78	22.9	−8.8	10.0	1.5	2.00	1.23	−2.5	+15.0
S Sge	0.92	23.0	−7.3	6.3	1.7	0.40	0.35	−10.3	+7.4
U Vul	0.90	23.8	−1.5	8.2	1.7	0.95	0.72	−11.7	+7.0
CN Lyr	0.37	25.5	+13.5	11.3	0.9	2.75	2.41*	+22.0	+41.8
X Vul	0.80	31.6	−2.4	9.2	1.5	1.38	0.95	−13.0	+5.2
SV Vul	1.66	31.7	−0.8	8.8	3.4	2.75	1.52	−2.5	+15.9
SU Cyg	0.59	32.4	+1.5	7.3	1.2	0.50	0.42	−35.8	−17.2
GH Cyg	0.89	34.2	−1.1	10.8	1.7	3.16	1.65	−16.5	+1.6
MW Cyg	0.78	38.7	−1.6	10.5	1.5	2.51	1.42	−13.0	+4.9
CD Cyg	1.23	38.8	+0.5	9.8	2.3	2.63	1.47	−11.0	+7.0
T Vul	0.65	40.0	−11.1	6.4	1.3	0.35	0.31	−1.4	+14.8
V383 Cyg	0.66	41.7	−3.6	12.8	1.3	6.61	2.49	−20.0	−2.8
GL Cyg	0.53	42.9	+3.4	14.6	1.1	13.80	4.54*	−58.5	−40.6
V343 Cyg	1.08	42.9	+3.3	14.8	2.0	22.91	12.70*	−93.0	−75.2
DT Cyg	0.40	44.5	−11.6	5.9	0.9	0.23	0.21	−0.5	+15.2
X Cyg	1.21	44.7	−5.1	7.4	2.3	0.87	0.67	+9.3	+25.9
VX Cyg	1.30	50.0	−4.2	10.4	2.5	3.80	1.84	−18.5	−2.4
VY Cyg	0.90	50.7	−5.3	10.7	1.7	3.02	1.61	−10.5	+5.3
MZ Cyg	1.33	51.3	−9.5	12.8	2.5	11.48	10.75*	−52.0	−37.0
SZ Cyg	1.18	52.1	+3.3	10.3	2.2	3.16	1.65	−17.0	−0.4
TX Cyg	1.17	52.1	−2.9	11.4	2.2	5.25	2.21	−19.0	−3.0
BZ Cyg	1.01	52.5	+0.8	11.6	1.9	5.01	2.15	−17.0	−0.8
V386 Cyg	0.72	53.3	−5.5	10.5	1.4	2.40	1.39	−16.5	−1.2
VZ Cyg	0.69	59.4	−9.0	9.5	1.4	1.51	1.01	−16.5	−2.8
BG Lac	0.73	60.9	−9.7	9.2	1.4	1.32	0.92	−19.5	−6.3
Y Lac	0.64	66.5	−4.3	8.6	1.3	0.95	0.72	−18.0	−5.1
AK Cep	0.86	72.7	+0.2	12.1	1.6	5.50	2.26	−52.5	−40.5
δ Cep	0.73	72.9	+0.4	4.2	1.4	0.13	0.12	−15.6	−3.6
RR Lac	0.81	73.4	−2.1	9.3	−1.5	1.45	0.98	−35.0	−23.6

TABLE 1—*Continued*

Star	log Period	l	b	Median m_{pg}	M_{pg}	Photometric Distance	Corrected Distance	Normal Velocity	V'
						kpc	kpc	km/sec	km/sec
Z Lac	1.04	73°5	− 1°7	9.1	−2.0	1.66	1.08	−25.0	− 13.6
V Lac	0.70	74.2	− 2.7	9.3	1.4	1.38	0.95	−20.0	− 8.9
X Lac	0.74	74.4	− 2.6	9.1	1.4	1.26	0.88	−26.5	− 15.4
SW Cas	0.74	77.4	− 1.6	9.9	1.4	1.82	1.16	−38.0	− 27.5
RS Cas	0.80	82.1	+ 0.9	11.6	1.5	4.17	1.95	−25.0	− 15.5
RY Cas	1.08	83.1	− 3.1	11.0	2.0	3.98	1.89	−70.0	− 61.3
46.1932 Cas	0.99	84.5	+ 0.7	11.0	1.9	3.80	1.84	−71.0	− 62.1
CG Cas	0.64	84.6	− 1.1	12.6	1.3	6.03	2.38	−87.0	− 78.7
SY Cas	0.61	86.0	− 3.9	9.7	1.2	1.51	1.01	−43.0	− 35.1
TU Cas	0.33	86.9	−11.2	8.3	0.8	0.66	0.53	−22.0	− 15.5
AP Cas	0.84	88.6	+ 0.4	12.5	1.6	6.61	2.49	−44.5	− 37.0
XY Cas	0.65	90.5	− 2.4	10.5	1.3	2.29	1.35	−42.0	− 35.4
VW Cas	0.78	92.4	− 0.7	11.1	1.5	3.31	1.70	−58.5	− 52.2
BP Cas	0.18	93.0	+ 3.1	11.6	0.6	2.75	1.48	−41.0	− 34.4
UZ Cas	0.63	93.2	− 1.2	11.9	1.3	4.37	2.00	−51.0	− 44.9
RW Cas	1.17	96.8	− 4.1	10.1	2.2	2.88	1.56	−63.0	− 58.4
BY Cas	0.51	97.3	− 0.2	12.0	1.1	4.17	1.95	−44.0	− 39.1
VV Cas	0.79	98.1	− 1.6	11.0	1.5	3.16	1.65	−50.5	− 46.2
VX Per	1.04	100.7	− 2.4	10.0	2.0	2.51	1.43	−33.0	− 29.5
SU Cas	0.29	101.0	+ 9.1	6.8	0.8	0.33	0.29	− 7.0	− 2.2
UX Per	0.66	101.3	− 2.5	12.6	1.3	6.03	2.38	−41.5	− 38.3
SZ Cas	1.13	102.5	− 0.6	10.8	2.1	3.80	1.84	−42.5	− 39.3
VY Per	0.74	102.8	− 1.0	12.3	1.4	5.50	2.26	−39.5	− 36.4
UY Per	0.73	103.6	− 0.7	12.4	1.4	5.75	2.32	−59.0	− 56.1
RW Cam	1.22	112.5	+ 4.6	9.4	2.3	2.19	1.31	−25.5	− 25.1
RX Cam	0.90	113.5	+ 5.6	8.7	1.7	1.20	0.86	−35.0	− 34.7
AS Per	0.70	121.8	+ 0.2	10.6	1.4	2.51	1.42	−25.5	− 28.6
SX Per	0.63	126.7	− 5.2	12.2	1.3	5.01	2.15	+ 5.5	+ 0.3
SV Per	1.05	130.3	− 0.3	9.3	2.0	1.82	1.16	− 9.5	− 15.3
SY Aur	1.01	132.4	+ 3.4	9.5	1.9	1.91	1.20	− 2.0	− 8.0
AN Aur	1.01	132.6	+ 0.2	11.8	1.9	5.50	2.26	− 9.5	− 16.0
RX Aur	1.07	133.5	0.0	8.3	2.0	1.15	0.83	−21.0	− 27.8
Y Aur	0.59	134.4	+ 5.6	9.7	1.2	1.51	1.01	+ 8.5	+ 2.2
AW Per	0.81	134.4	− 4.1	8.8	1.5	1.15	0.83	+13.5	+ 5.9
YZ Aur	1.26	135.0	+ 2.2	10.8	2.4	4.37	2.00	−20.5	− 27.5
AO Aur	0.83	145.3	+ 3.4	11.7	1.6	4.57	2.05	−14.5	− 24.3
SZ Tau	0.50	147.4	−17.3	7.0	1.1	0.42	0.36	− 3.2	− 15.6
AS Aur	0.5	150.0	+ 5.1	11.8	1.1	3.80	1.84	+10.5	− 0.5
RT Aur	0.57	150.8	+10.3	6.0	1.2	0.28	0.25	+21.4	+ 11.1
AA Gem	1.05	152.4	+ 4.1	10.6	−2.0	3.31	1.70	+ 9.5	− 2.0

TABLE 1—*Continued*

Star	log Period	l	b	Median m_{pg}	M_{pg}	Photometric Distance	Corrected Distance	Normal Velocity	V'
						kpc	kpc	km/sec	km/sec
RZ Gem. . .	0.74	155°.4	+ 1°.4	10.6	−1.4	2.51	1.43	+ 6.5	− 6.3
SW Tau. . . .	0.20	158.0	−28.4	9.5	0.6	1.05	0.97*	+17.0	+ 1.8
ST Tau. . . .	0.61	160.8	− 6.6	8.7	1.2	0.95	0.72	+ 1.0	− 13.8
AD Gem. . .	0.58	160.9	+ 9.1	9.9	1.2	1.66	1.08	+36.0	+ 23.1
ζ Gem. . .	1.01	163.4	+13.4	4.5	1.9	0.19	0.18	+ 6.8	− 5.9
CR Ori.	0.69	163.6	− 2.4	12.8	1.4	6.92	2.55	+40.5	+ 25.6
RS Ori.	0.88	164.3	+ 1.8	9.2	1.7	1.51	1.01	+42.0	+ 27.3
W Gem. . .	0.90	165.1	+ 4.8	7.4	1.7	0.66	0.53	− 0.7	− 14.9
CS Ori.	0.59	165.7	− 3.0	11.5	1.2	3.47	1.75	+15.5	+ 0.2
WW Mon. . . .	0.67	170.4	+ 1.8	13.6	1.3	9.55	2.98	+56.5	+ 40.7
T Mon. . . .	1.43	171.3	− 1.1	7.3	2.7	1.00	0.75	+32.0	+ 15.8
SV Mon. . . .	1.18	171.4	− 2.2	9.4	2.2	2.09	1.27	+26.5	+ 10.2
TZ Mon. . . .	0.87	181.7	+ 2.7	11.6	1.7	4.57	2.05	+34.0	+ 16.7
SZ Mon. . . .	1.21	181.8	+ 0.8	12.1	2.3	7.59	2.67	+35.0	+ 17.5
TX Mon. . . .	0.94	181.8	+ 0.7	11.5	1.8	4.57	2.05	+51.0	+ 33.4
XX Mon. . . .	0.7	183.2	+ 0.3	11.5	1.4	3.80	1.84	+64.5	+ 46.7
AC Mon. . . .	0.90	189.4	− 0.5	10.8	1.7	3.16	1.65	+40.5	+ 22.2
RY CMa. . .	0.67	193.7	+ 1.6	9.0	1.3	1.15	0.83	+37.5	+ 19.1
TV CMa. . .	0.67	194.9	− 1.0	11.9	1.3	4.37	2.00	+39.0	+ 20.3
TW CMa. . .	0.85	196.8	+ 1.4	10.6	1.6	2.75	1.52	+66.5	+ 48.0
176.1932 CMa	0.6	196.8	−15.1	9.5	1.2	1.38	1.11*	+56.5	+ 36.7
RW CMa. . .	0.76	199.7	− 2.6	12.0	1.5	5.01	2.15	+50.0	+ 31.0
VW Pup. . . .	0.63	203.1	+ 0.6	12.5	1.3	5.75	2.32	+24.0	+ 5.2
X Pup. . . .	1.41	203.8	+ 0.4	9.4	2.7	2.63	1.47	+61.5	+ 42.7
VX Pup. . . .	0.48	204.7	− 0.1	8.6	1.0	0.83	0.64	+12.0	− 6.8
WW Pup. . . .	0.74	205.1	+ 2.1	10.9	1.4	2.88	1.56	+87.0	+ 68.5
SS CMa. . .	1.09	206.9	− 3.0	11.4	2.0	4.79	2.10	+60.0	+ 41.0
WX Pup. . . .	0.95	209.2	− 0.2	10.7	1.8	3.16	1.65	+49.0	+ 30.4
WY Pup. . . .	0.72	209.5	+ 3.8	11.1	1.4	3.16	1.65	+44.0	+ 25.9
WZ Pup. . . .	0.70	209.6	+ 4.4	12.1	1.4	5.01	2.15	+64.0	+ 46.0
AD Pup. . . .	1.13	209.6	+ 1.1	10.5	2.1	3.31	1.70	+67.5	+ 49.0
VZ Pup. . . .	1.36	211.1	− 2.2	11.6	2.6	6.92	2.55	+49.0	+ 30.1
AQ Pup. . . .	1.48	213.9	+ 1.1	10.0	2.9	3.80	1.84	+41.0	+ 22.8
RS Pup. . . .	1.62	220.1	+ 0.7	8.4	3.2	2.09	1.27	+19.0	+ 1.2
AT Pup. . . .	0.82	222.0	− 0.7	8.7	1.6	1.15	0.83	+24.5	+ 6.8
AP Pup. . . .	0.71	223.1	− 4.9	8.1	1.4	0.79	0.62	+42.5	+ 24.5
β Dor. . . .	0.99	238.5	−32.3	5.0	1.9	0.24	0.22	+ 5.8	− 10.5
l Car. . . .	1.55	250.7	− 6.8	4.8	3.0	0.36	0.32	+ 4.1	− 8.9
S Mus. . . .	0.98	267.1	− 7.8	6.9	1.8	0.55	0.46	0.0	− 8.9
R TrA. . . .	0.53	284.5	− 8.4	7.1	−1.1	0.44	0.38	−18.9	− 22.8

TABLE 1—*Continued*

Star	log Period	l	b	Median m_{pg}	M_{pg}	Photometric Distance	Corrected Distance	Normal Velocity	V'
						kpc	kpc	km/sec	km/sec
W Vir	1.24	289°.3	+57°.6	10.4	−2.3	3.47	3.44*	−66.0	− 60.8
S TrA	0.80	289.6	− 9.0	6.9	1.5	0.48	0.41	+ 2.0	0.0
S Nor	0.99	295.3	− 6.3	7.1	1.9	0.63	0.51	− 6.5	− 6.5
κ Pav	0.96	295.4	−26.3	5.1	1.8	0.24	0.22	+36.5	+ 34.4
AL Vir	1.01	299.9	+44.2	9.9	1.9	2.29	2.25*	+23.0	+ 29.7
RX Lib	1.40	316.3	+25.6	12.6	2.7	11.48	11.39*	−58.0	− 48.1
RV Sco	0.78	318.2	+ 4.4	7.6	1.5	0.66	0.53	−17.5	− 9.0
RY Sco	1.31	324.2	− 4.8	8.9	2.5	1.91	1.20	−17.5	− 8.2
BF Oph	0.61	324.9	+ 7.2	8.2	1.2	0.76	0.60	−31.5	− 20.6
X Sgr	0.85	328.9	− 1.2	5.1	1.6	0.22	0.20	−13.5	− 2.4
W Sgr	0.88	329.2	− 5.4	5.2	1.7	0.24	0.22	−25.0	− 14.5
AP Sgr	0.70	335.8	− 3.9	7.7	1.4	0.66	0.53	−18.0	− 5.8
VY Sgr	1.13	337.8	− 2.5	13.0	2.1	10.47	3.10	− 6.0	+ 7.0
WZ Sgr	1.34	339.8	− 2.8	9.0	2.5	2.00	1.23	−11.0	+ 2.3
Y Sgr	0.76	340.5	− 3.7	6.2	1.5	0.35	0.31	− 3.2	+ 10.4
AY Sgr	0.82	341.0	− 3.9	12.0	1.6	5.25	2.21	−26.5	− 13.9
U Sgr	0.83	341.4	− 5.9	7.9	1.6	0.79	0.62	− 2.0	+ 11.2
V350 Sgr	0.71	341.4	− 9.4	8.0	1.4	0.76	0.60	+ 9.5	+ 22.4
V377 Sgr	1.21	342.2	− 9.8	14.3	2.3	20.89	20.20*	− 5.0	+ 8.0
BB Sgr	0.82	342.3	−10.5	7.6	1.6	0.69	0.55	+ 7.5	+ 20.4
XX Sgr	0.81	342.7	− 3.4	9.5	1.5	1.58	1.05	+ 2.5	+ 16.7
YZ Sgr	0.98	345.4	− 8.6	8.0	1.8	0.91	0.69	+18.5	+ 32.3
V410 Sgr	1.14	345.7	−12.9	13.3	2.1	12.02	11.64*	+ 5.0	+ 18.2
X Sct	0.62	346.7	− 3.1	10.4	1.3	2.19	1.31	+ 7.0	+ 21.8
UZ Sct	1.17	346.9	− 3.0	12.4	2.2	8.32	2.79	+12.0	+ 26.9
Y Oph	1.23	348.3	+ 8.7	7.3	2.3	0.83	0.64	− 6.1	+ 10.2
Y Sct	1.01	351.7	− 2.3	10.4	1.9	2.88	1.56	+ 6.5	+ 22.5
SS Sct	0.56	352.9	− 3.3	8.4	1.2	0.83	0.64	−14.0	+ 2.0
Z Sct	1.11	354.5	− 2.2	10.4	2.1	3.16	1.65	+29.5	+ 45.9
TY Sct	1.04	355.7	− 1.4	12.6	2.0	8.32	2.79	+ 6.5	+ 23.1
RU Sct	1.29	355.9	− 1.2	10.6	2.4	3.98	1.89	−14.0	+ 2.8
BW Sct	0.58	355.9	− 2.7	12.7	1.2	6.03	2.38	+ 1.5	+ 18.0
BX Sct	0.81	356.6	− 3.2	13.9	1.5	12.02	3.30	−17.5	− 1.1
AA Ser	1.23	358.5	+ 0.3	14.6	2.3	23.99	4.36	− 5.5	+ 11.7
PZ Aql	0.94	358.6	− 3.8	13.0	1.8	9.12	2.91	−32.0	− 15.4
U Aql	0.85	358.7	−13.1	7.3	−1.6	0.60	0.49	− 7.0	+ 8.2

on $\alpha = 12^h40^m$, $\delta = +28°$ (1900) for the galactic pole. The median apparent photographic magnitudes of the fifth column are taken from various sources, but mostly from the Harvard publications. In cases where photographic magnitudes were not available they have been calculated from visual estimates by applying the color index appropriate to the period and spectral type. Unfortunately, it does not seem possible to reduce the magnitudes to a uniform scale and they must be considered as first approximations to the true values. Probably the absolute photographic magnitudes of the sixth column, which were derived from the period-luminosity relationship,[2] are, in general, more accurate, with only small uncertainty as to the zero point. The distances, in kiloparsecs, given in the seventh column are derived from the equation

$$5 \log \pi = M - m - 5 .$$

The next column shows the value of the distance, corrected for uniform space-absorption of 0.85 mag/kpc. Asterisks mark the stars which lie outside the assumed stratum. In the distances given for these stars account is taken of the fact that the absorption is effective for only a portion of the path from the star to the earth. The observed normal radial velocity for each star is given in the ninth column, and the velocity, corrected for a solar motion of 20 km/sec toward the apex, $\alpha = 271°$, $\delta = 28°$, in the last column. The assumption that the normal velocity taken from the velocity-curves is that of the center of mass of the star seems justified by the comparatively small value of the K-term resulting from the solutions.

II. DISTRIBUTION

The galactic distribution of the Cepheids whose radial velocities have been measured is shown in Figure 1. The stars are plotted according to galactic longitude and latitude. It will be noted immediately that there is a high concentration toward the galactic equator. One hundred and thirty-six stars (87 per cent) lie within 10° and 105 (67 per cent) within 5° of the plane of the galaxy. Omitting six stars whose latitudes are numerically greater than ±20°,

[2] Shapley, *Star Clusters*, p. 135, 1930.

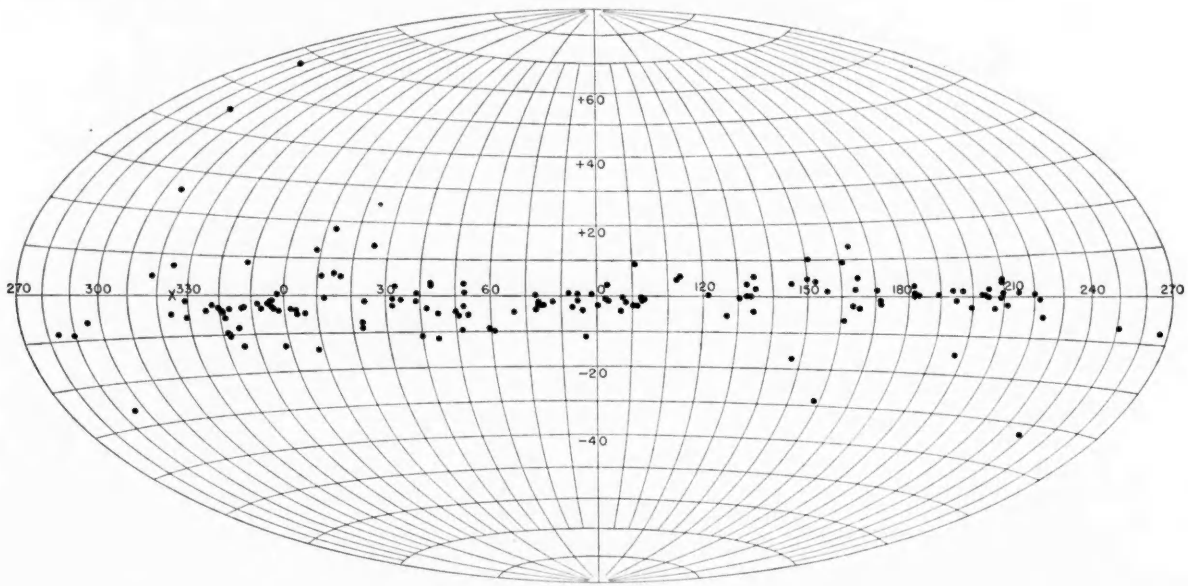


FIG. 1.—Distribution of Cepheids for which radial velocities have been measured. The co-ordinates are galactic longitude and latitude. The direction to the center is indicated by ×.

we find the mean latitude to be $-1\overset{\circ}{.}4$. If distances are taken from the period-luminosity relationship and allowance is made for a general uniform absorption of 0.85 mag/kpc, all the stars except thirteen (176.1932 CMa, GL Cyg, MZ Cyg, V343 Cyg, BL Her, RX Lib, CN Lyr, BH Oph, V377 Sgr, V410 Sgr, SW Tau, W Vir, AL Vir) are found to be situated within the assumed absorbing stratum.

In longitude the distribution is fairly uniform over the region observable from northern observatories, although there is some evidence of a decrease in the number of stars in the direction of the center and in the region 115°–130°, which is nearly opposite.

In Figure 2 the δ Cepheids within 3 kpc of the sun are projected upon the plane of the galaxy. Stars for which spectroscopic observations are available are indicated by dots and others by small circles. On account of uncertainty as to their distances, stars which are known to be located in regions of heavy obscuration are omitted. The distances used have been corrected for the effect of space-absorption of 0.85 mag/kpc. This plot gives a good representation of the distribution of 214 Cepheids with reference to the sun, which is located at the center. Except in a few cases their distances from the plane are relatively small. The large Carina group, longitude 250°–270°, is remarkable. At longitude 90° there is a somewhat similar concentration of Cepheids in the Cassiopeia region. Taken together, these groups, which are much scattered in distance from the sun, suggest an arm of the Milky Way. A band 1 kpc in width along this arm, as indicated by the dashed lines of the figure, contains 58 per cent of the known δ Cepheids. The trend of the arm appears to be more or less convex toward the center. Such a curvature would hardly be expected in the inner part of a spiral, but might be possible as a local distortion in the outer portion of an open type of galactic structure. The sun is near the axis of the arm and not in a region of low density as found by Oort[3] in a study of the distribution of faint stars in Kapteyn's Selected Areas.

Another striking feature of the diagram is the complete absence of δ Cepheids at distances greater than 1.3 kpc between longitudes 301° and 347°. Heavy obscuration doubtless prevents the discovery

[3] *B.A.N.*, **8**, 233, 1938.

of distant variables at low latitudes in the general direction of the center.

Few radial velocities are available in the quadrant 230°–320°, on account of the southern declinations involved.

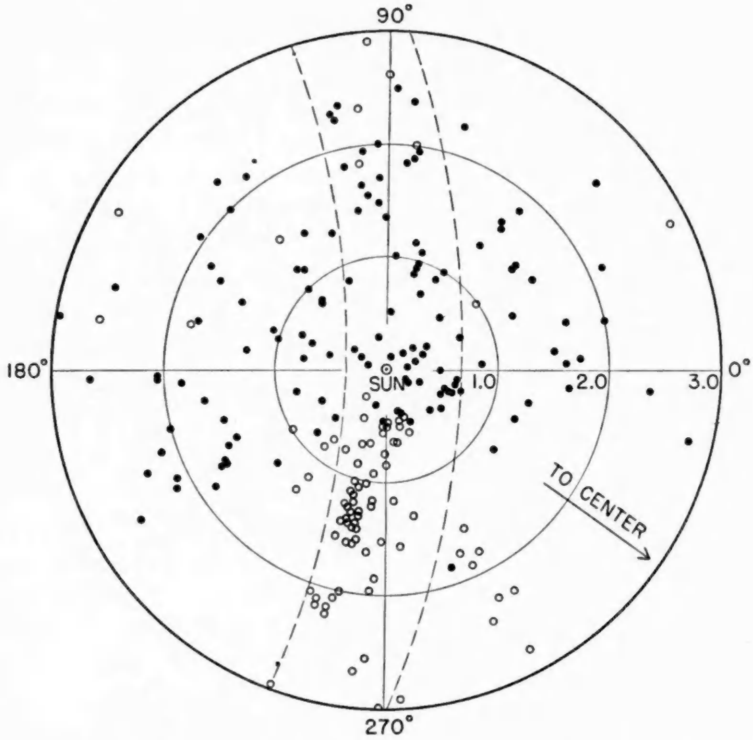


FIG. 2.—Projection on the plane of the galaxy of 214 Cepheids within a distance of 3 kpc of the sun. Stars with measured radial velocities are represented by dots, others by circles.

Table 2 gives the two-dimensional density of known variables as plotted in Figure 2, and the number to be expected in zones concentric about the sun on the basis of uniform distribution in the plane of the galaxy.

The marked clustering of Cepheids about the sun may be attributed to one or more of three causes: (1) *local cluster*—there may actually be a local concentration of stars in the neighborhood of the sun, possibly forming a knot in an arm of the Milky Way; (2) *in-*

sufficient correction for absorption—a further reduction in the distances by increasing the absorption coefficient would have its greatest effect on the outlying stars and would tend toward more uniform distribution (it is doubtful, however, whether the moderate additional absorption which other considerations permit would greatly improve the distribution in this respect); (3) *the number of undiscovered variables of this type increases with distance*—although discovery lists of recent years have added surprisingly few δ Cepheids, it seems quite certain that many are yet to be detected among the fainter stars.

TABLE 2

DISTRIBUTION OF CEPHEIDS

(Distance corrected for absorption of 0.85 mag/kpc)

Zone	No.	Average Density	Expected No. Reduced to Uniform Distribution
kpc from sun		per kpc²	
0.0–0.4	16	31.8	16
0.4–0.8	39	25.9	48
0.8–1.2	32	12.9	80
1.2–1.6	45	12.8	112
1.6–2.0	32	7.1	144
2.0–2.4	31	5.5	176
2.4–2.8	13	2.0	208

III. GALACTIC ROTATION

Consideration of the distribution of δ Cepheid variables indicates that, except for the lack of observations in the quadrant of the Milky Way observable only from the Southern Hemisphere, they are particularly well situated for a study of galactic rotation based on radial velocities. On the other hand, for a determination of the solar motion and the location of its apex, their concentration toward the plane of the galaxy, together with the absence of observations of southern stars, gives an unbalanced solution of low weight, especially for the declination of the apex. For this reason and also because of Milne's[4] conclusions in regard to the use of the "local" solar motion, the measured radial velocities have been corrected for a standard

[4] *M.N.*, **95**, 564, 1935.

value of 20 km/sec toward the apex $\alpha = 271°$, $\delta = +28°$, and no solar motion terms have been included in the final solutions.

One of the outstanding advantages of the use of Cepheid variables for the study of galactic rotation effects is that, although the stars are among the most distant observable for radial velocity, their distances can readily be determined by the use of apparent magnitudes and the absolute magnitudes based on Shapley's period-luminosity curve. The distances thus derived are known as "photometric" distances but, unfortunately, they are subject to considerable uncertainty on account of the effect on the apparent magnitudes of general and selective absorption in space. As a first approximation, for the purposes of this study, the absorbing material is assumed to be of a uniform structure and to lie along the plane of the galaxy in a stratum the total thickness of which is 0.4 kpc. The solutions for rotation afford a method for estimating the effective total absorption.

The general solutions for galactic rotation follow the methods of Oort,[5] and the papers of Hayford,[6] Bottlinger,[7] Plaskett and Pearce,[8] and Berman[9] have also been used extensively. The results of the preliminary solutions,[10] to which reference has been made by van Rhijn,[11] have been somewhat altered by the use of additional material obtained from later observations.

Radial velocities for 156 Cepheids are available for the study of galactic rotation. The radial velocities of these stars, corrected for solar motion, are plotted according to galactic longitude in Figure 3. In the solutions it seems advisable, however, to omit 176.1932 CMa, for which no period is known, and two stars (W Vir, AL Vir) which are peculiar in some respects and whose galactic latitudes (44°, 57°) are excessive. Four stars (κ Pav, BB Her, VW Pup, AP Her) have been omitted on account of large residuals. Fourteen stars (FM Aql, PZ Aql, TX Cyg, BZ Cyg, GH Cyg, XX Sgr, VY Sgr, AY Sgr, Y Sct, RU Sct, TY Sct, BX Sct, AA Ser, X Vul) are situated

[5] *Op. cit.*, **3**, 275, 1927.

[6] *Lick Obs. Bull.*, **16**, 53, 1932.

[7] *Veröff. Berlin Babelsberg*, **10**, Heft 2, 1933.

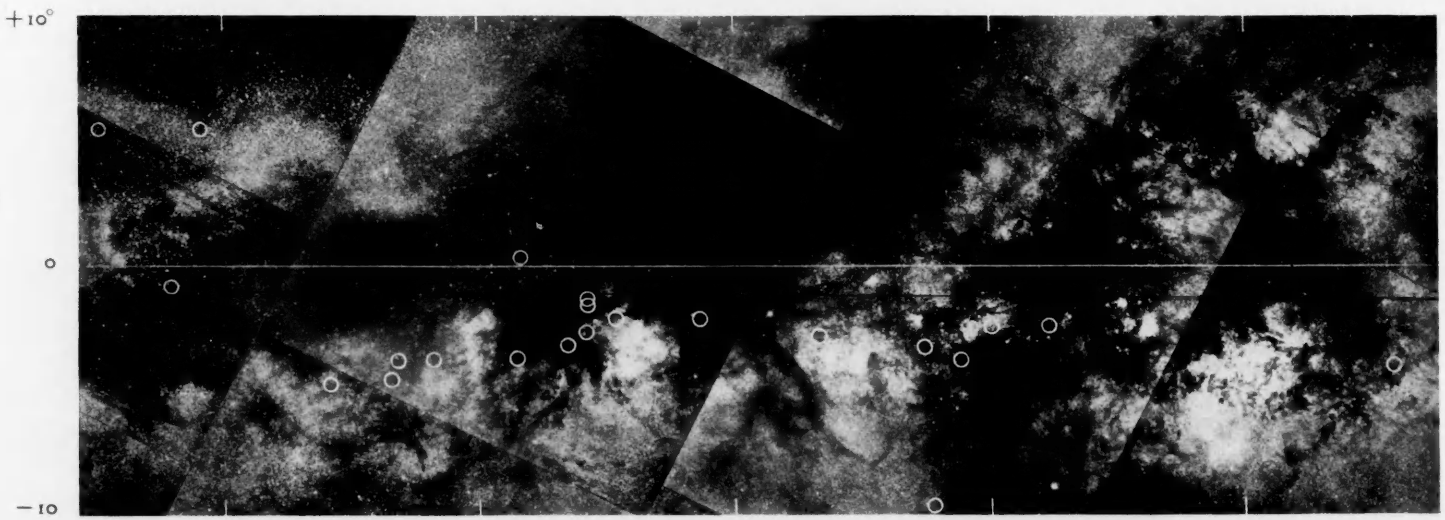
[8] *Pub. Dom. Ap. Obs.*, **5**, 242, 1936.

[9] *Lick Obs. Bull.*, **18**, 57, 1937.

[10] *Pub. A.S.P.*, **45**, 202, 1933; *Pub. A.A.S.*, **7**, 218, 1933.

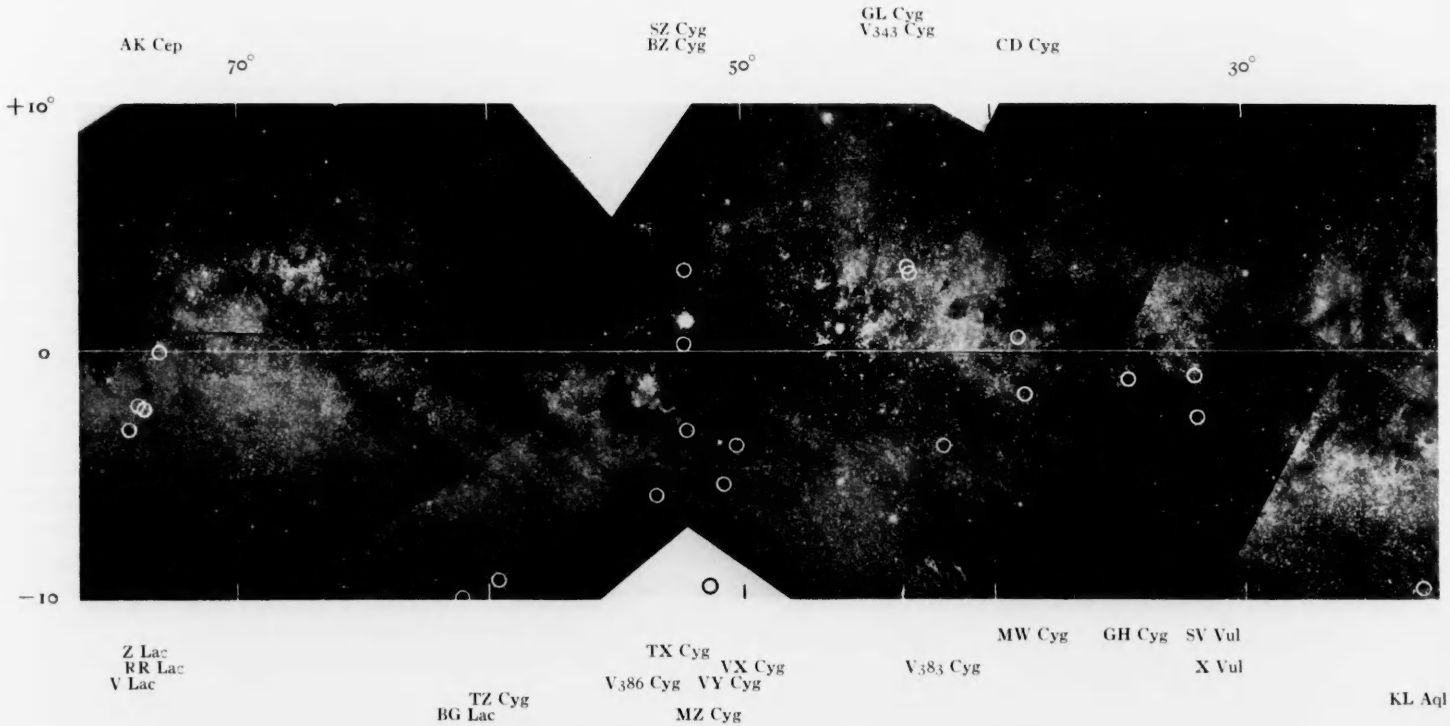
[11] *Pub. Kapteyn Astr. Lab.*, No. 47, 1936.

PLATE XXI



Milky Way from Photographs by Ross; Longitudes 322°–16°
The location of distant Cepheids is indicated by circles

PLATE XXII



Milky Way from Photographs by Ross; Longitudes 22°–76°

The location of distant Cepheids is indicated by circles

in regions of heavy obscuration and could not be used because of uncertainty in their distances. The location of these stars with reference to dark clouds, as well as that of other distant Cepheids in the same Milky Way regions between longitudes 320° and 75°, is shown in Plates XXI and XXII.

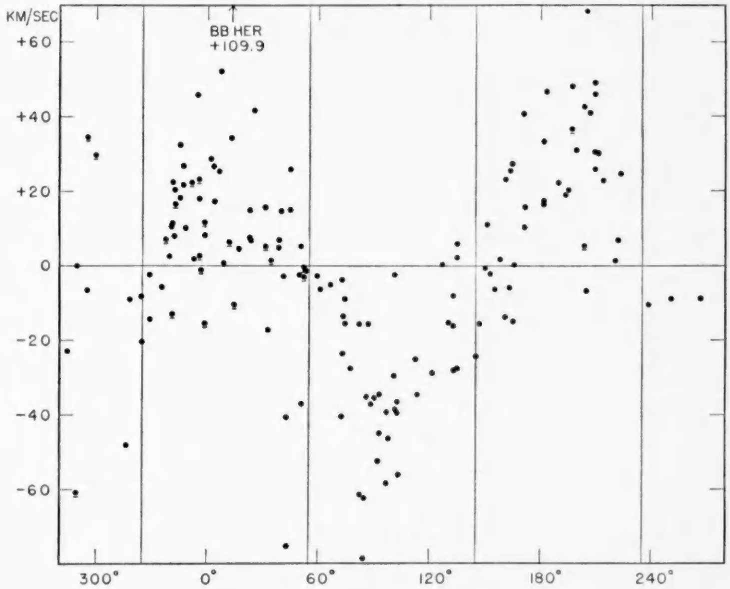


FIG. 3.—Plot showing the velocities of 156 Cepheids according to galactic longitude. Stars omitted from the solutions are underlined.

The remaining stars, 135 in number, have been separated according to distance into five groups as shown in the accompanying tabulation.

Group	No.	Photometric Distance
1	35	0.13– 0.91 kpc
2	33	0.95– 2.40
3	34	2.51– 4.17
4	26	4.37– 9.55
5	7	10.00–22.91

The first four groups were used for the solutions for galactic rotation. The stars of group 5 are too few and too scattered to be considered as a complete group.

Least-squares solutions were undertaken for each of the four groups, with the aid of the known values for the longitude, latitude, distance, and velocity. The equation of condition for each star was of the form

$$rA \sin 2(l - l_0) \cos^2 b = V' ,$$

where l, b are the galactic co-ordinates of the star; rA is the rotational term for a given distance r; l_0 is the galactic longitude of the center of rotation; and V' is the radial velocity of the star corrected for a solar motion of 20 km/sec. The equations were given equal weight.

The resulting values of A, the rotational term for a distance of one kpc, of $\bar{r}A$, and of l_0 are given in Table 3.

TABLE 3

GROUP SOLUTIONS WITHOUT ABSORPTION CORRECTION

Group	No.	$\bar{r}$	A	$\bar{r}A$	l_0
		kpc	km/sec	km/sec	
1	35	0.52	19.9	10.4	331°2
2	33	1.56	14.5	22.7	323.2
3	34	3.20	12.2	38.9	326.5
4	26	5.56	6.8	37.7	327.0

IV. INTERSTELLAR ABSORPTION

The values found for the rotational constants furnish a means of estimating the effect of interstellar absorption upon the photometric distances. The results of the solution are consistent for l_0, but the values found for A do not show the agreement which would be expected if the differential rotational effect varies directly with distance in the region occupied by these stars. The discrepancy can be reasonably explained, in part at least, by assuming that the photometric distances, which depend upon observations of apparent magnitudes, are affected by considerable absorption in space.

The fact that the distant group 4 shows a rotation effect which is actually less than that of the nearer group 3 is surprising and makes the determination of an absorption coefficient difficult and uncertain. Although the observations of the stars of group 4 are mostly made

with lower dispersion than those of the nearer groups, there is no reason to doubt their essential accuracy for mean results. Either there is a breaking-down of the rotation effect at great distances in a way which cannot be accounted for by the inclusion of higher-order terms in the equations or the absorption coefficient is greater for the stars of group 4. This would mean that these stars, in the mean, are situated in regions of greater obscuration than those of the nearer groups. Perhaps star counts could be made which would give information on this point.

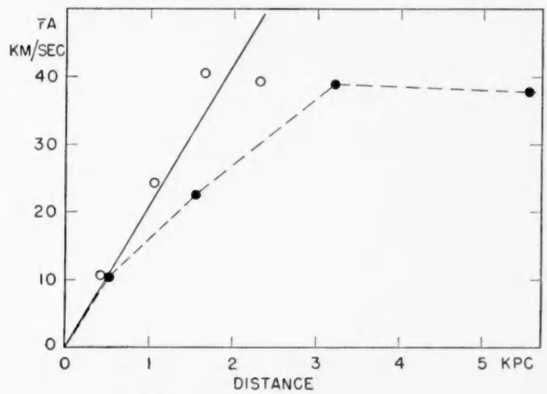


FIG. 4.—Rotation effect and distance. The broken line indicates the value of $\bar{r}A$ for photometric distances; the straight line gives the result when an absorption coefficient of 0.85 mag/kpc is introduced.

Recent observations of interstellar calcium and sodium indicate that the gases in space are not uniformly distributed. In the existing state of our knowledge it may not be possible to set a definitive value for the absorption throughout the galaxy. The result from one group of stars may well be quite different from that given by another group, depending on their positions and distances.

Apparently the best that we can hope for at present is to adopt for our final solutions a value for the absorption coefficient which, on the assumption of constant A, will serve as a first approximation.

By means of cut-and-try methods it was found that by correcting the magnitudes for a total uniform absorption of 0.85 mag/kpc (photographic) a fair representation of the observations is obtained. The results, determined with and without corrections for absorp-

tion, are shown in Figure 4. The dots represent the values of the semi-amplitude plotted against the mean distance without correction for absorption. The circles give the same after applying the correction of 0.85 mag/kpc. The straight line shows the mean variation of $\bar{r}A$ with distance and corresponds to a value for A of 20.9 km/sec.

Another method for estimating the absorption coefficient has been suggested by Bottlinger and Schneller.[12] In all probability the average thickness of the stratum containing Cepheid variables is the same in different parts of the galaxy. Hence, we should expect

TABLE 4

MEAN DISTANCES OF CEPHEIDS FOR DIFFERENT VALUES OF ABSORPTION

(Unit, 1 kpc)

Group	No Absorption		0.85 Mag. Absorption		1.50 Mag. Absorption	
	x	z	x'	z'	x''	z''
1	0.46	0.064	0.38	0.058	0.33	0.052
2	1.39	.093	0.94	.062	0.80	.054
3	2.92	.140	1.57	.072	1.20	.055
4	5.40	0.170	2.22	0.069	1.65	0.051

that the mean of the z co-ordinates of the stars would be the same at all distances from the sun. If, however, photometric distances are used and interstellar absorption is present, the mean value of z will increase with increasing distance. By varying the amount of absorption it is then possible to find the coefficient which gives z a constant value. The distances of the Cepheids from the plane of the galaxy have been computed and the average taken for each of four groups selected according to projected distance from the sun (x coordinate). The results for the stars in the velocity list are shown in Table 4. Stars of high galactic latitude and those located in regions of excessive obscuration are omitted. The four groups contain thirty-two stars each. The results indicate that, if the mean z components are to be equal at all distances from the sun, a correction corresponding to a mean total absorption of about 1.50 mag/kpc

[12] *Zs. f. Ap.*, 1, 340, 1930.

(photographic) must be applied. This value for the absorption correction may, perhaps, be considered as an upper limit. The criterion should not be applied too strictly because, in the neighborhood of the center of the system and perhaps in other regions of local clustering, we may expect that the stratum will be thicker. Group motions, unless exactly in the plane of the galaxy, tend to increase the values of the z components in certain regions. Also, for a given distance, stars with high galactic latitudes will be brighter, if absorption is limited to layers near the plane, and their variability will be more readily detected. This will increase the mean value of z, especially in the distant groups.

V. SOLUTIONS FOR ROTATION INCLUDING ABSORPTION

After introducing an absorption coefficient of 0.85 mag/kpc, new rotation solutions were made for the identical groups of the first

TABLE 5

GROUP SOLUTIONS WITH 0.85 MAG/KPC ABSORPTION

Group	$\bar{r}'$	A	$\bar{r}'A$	l_0
	kpc	km/sec	km/sec	
1	0.42	25.1 ± 4.8	10.6	$332\overset{\circ}{.}2\pm5\overset{\circ}{.}4$
2	1.06	22.8 ± 1.6	24.3	323.5 ± 2.0
3	1.66	24.5 ± 1.6	40.6	326.5 ± 2.3
4	2.31	17.1 ± 1.3	39.4	325.2 ± 2.6
Mean	....	20.9 ± 0.8	....	325.3 ± 1.3

solution with the results given in Table 5. The distances of the stars of the outer groups are greatly reduced. For example, when allowance for absorption is made, the distance of WW Mon, the most remote star of group 4, is changed from 9.55 to 2.99 kpc. This shows conclusively why it is that variables, lying within the stratum of absorption, have not been found at greater distances. Under such conditions the brightest Cepheid, if located within the absorbing medium at a distance of 10 kpc or farther, would at median brightness appear fainter than the twentieth magnitude.

The second solution shows little change in the longitude of the direction to the center. The value of $325\overset{\circ}{.}3$ seems to be accurately determined, as far as these stars are concerned. The value of A is

not so satisfactory. In the preliminary solution of 1933 a value of 18.5 km/sec was found with the same absorption coefficient, but this is now considerably increased by the inclusion of a number of additional observations and the omission of several stars used in the preliminary discussion.

The residual term K has not been introduced in the final solutions. The lack of observations of southern variables makes its evaluation somewhat uncertain. Its mean value found from a single solution, including the stars of all groups with distances corrected for absorption, is -3.8 km/sec. Because its physical significance is doubtful, it was thought better to omit it altogether and throw the whole weight of the observations into l_0 and A. Its inclusion, however, makes very little difference in the results.

The velocities for the four groups are plotted separately in Figure 5; the curves are those corresponding to the results found from the solutions.

VI. DISTANCE TO THE CENTER OF ROTATION

The distance to the center was determined by the simple relation[13]

$$2R_0 \cos (l_1 - l_0) = 2R_0 \cos (l_0 - l_3) = r ,$$

which is based on the condition that the rotational velocity of any star at the same distance from the center as the sun has zero velocity relative to the sun. R_0 is the distance, sun–center; r is the distance, sun–star; and l_1, l_3 are the longitudes of the two points nearest l_0, the direction of the center, where the velocity-curves drawn through the observations cross the zero-axis. Thirteen stars of groups 2 and 3, located near longitude 55° where the curve is practically a straight line, were used for this purpose. Their velocities were reduced to a mean distance, and the longitude at zero-velocity was determined for each group. The values of R_0, the distance to the center, found for groups 2 and 3 are 11.7 and 7.3 kpc, respectively, and the weighted mean is 10.0 kpc. Unfortunately, there are no stars near l_3, at longitude 235°, which could be used to increase the weight of the determination.

[13] Hayford, *op. cit.*, **16**, 73, 1932.

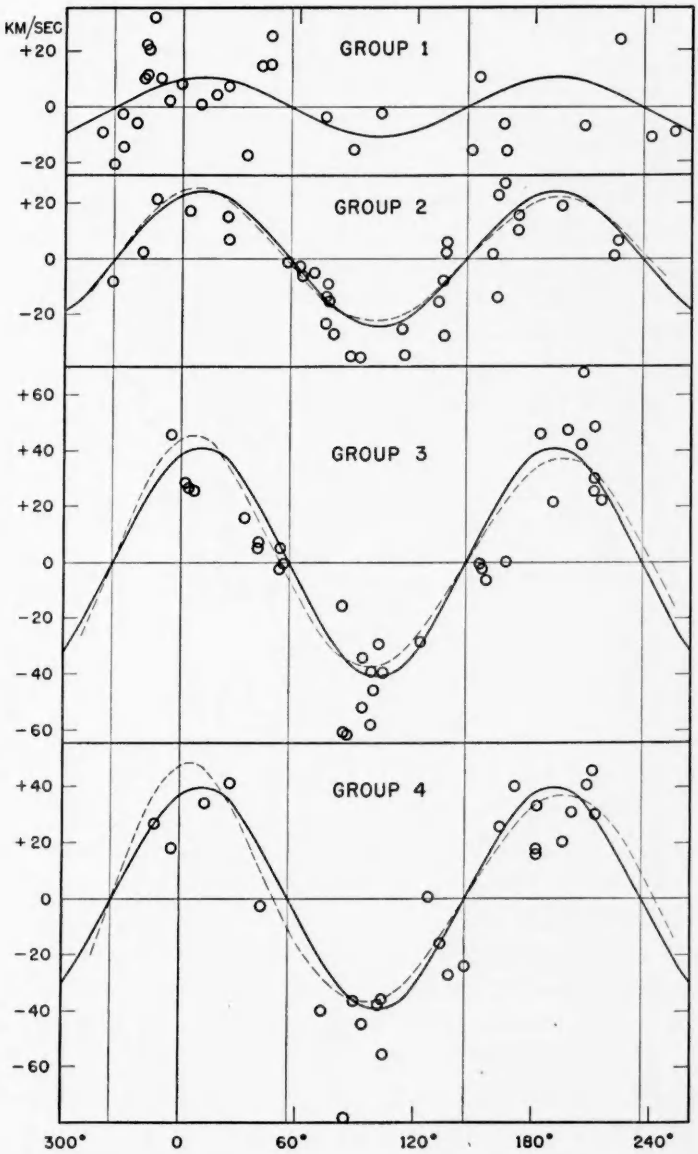


FIG. 5.—Rotational curves for groups 1–4. The velocities used in the solutions are plotted against galactic longitude. The continuous curve represents the Oort solution; the dashed curve includes the higher-order terms according to Bottlinger's formula.

VII. THE SUN'S ORBITAL VELOCITY AND THE EFFECT OF HIGHER ORDER TERMS

After allowance is made for absorption in space, all the stars used in the solutions are found to be less than 3 kpc distant. The effect of harmonic terms of higher order would not be expected to be large for stars whose distance is less than one-third that to the center; nevertheless, the effect can be detected in the curves for the three more distant groups. Instead of solving for constants of the power-series whose physical interpretations are in most cases doubtful, it seems sufficient to use Bottlinger's[14] trigonometric expansion of the fundamental force equation where the mass is concentrated at the center and the force varies inversely with the square of the distance from the center. The equation is

$$V' = \tfrac{3}{4} V_0 \frac{r}{R_0} \left[\sin 2l + (\tfrac{7}{8} \sin 3l - \tfrac{1}{8} \sin l) \frac{r}{R_0} + (\tfrac{77}{96} \sin 4l - \tfrac{14}{96} \sin 2l) \frac{r^2}{R_0^2} + \ldots \right],$$

where V' is the radial velocity of the star and V_0 is the rotational velocity of the sun in a circular orbit; l is the longitude measured from the direction to the center. By substituting 10.0 kpc for R_0 and the mean values of r for groups 2, 3, and 4, it is now possible to draw velocity-curves for different values of the solar velocity, V_0, and, by trial, to find the solar velocity which makes the sum of the squares of the residuals from the curve a minimum. In this way values of V_0 for groups 2, 3, and 4 were found to be 305, 330, and 245 km/sec, respectively. The weighted mean value is 296 km/sec, which corresponds to a period of revolution of 207,000,000 years.

In Figure 5 the dotted lines show the curves computed by the use of Bottlinger's formula. Because of the nearness of the stars as compared with the distance to the center, the differences between the two curves for each group are small.

By the use of the more rigorous formula including the second-order terms, the sum of the squares of the residuals is reduced by 10 per cent for group 3 but, in groups 2 and 4, little or no improvement

[14] *Loc. cit.*

in the fit appears. The distribution of the stars in longitude is not altogether satisfactory for this determination.

VIII. GROUP 5—THE MOST DISTANT CEPHEIDS

The stars of group 5, whose distances are so great that they cannot be included among the stars of group 4, are V 343 Cyg, GL Cyg,

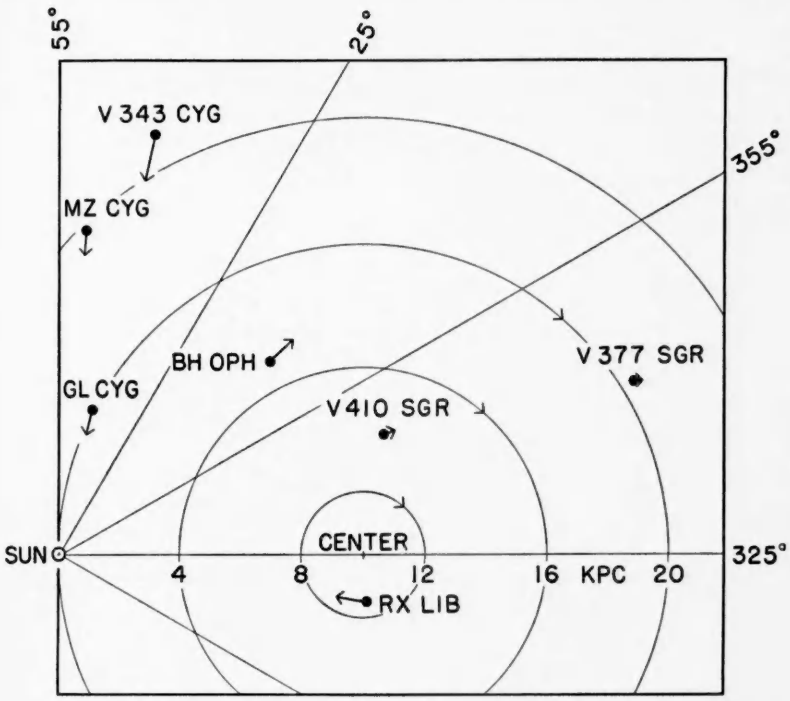


FIG. 6.—The projected positions of the stars of group 5 with respect to the sun and the center of rotation. The relative radial velocities are indicated by arrows from each star.

MZ Cyg, BH Oph, RX Lib, V 377 Sgr, and V 410 Sgr. The projected position of these stars, with respect to a center at a distance of 10 kpc, is shown in Figure 6. Circles about the center are drawn at distances of 4 kpc. The relative radial velocities are indicated by arrows. GL Cyg and V 377 Sgr have nearly the same distance from the center as the sun and would be expected to have low radial velocities. That of GL Cyg, −40.6 km/sec, is discordant. For the

five remaining stars the motion is in the right direction. The radial velocities of RX Lib and V 410 Sgr are smaller than would be expected. Both have rather high galactic latitudes which suggest large peculiar motions. It may be that these stars are associated with the central aggregation of matter which does not partake of planetary motion.

The velocities of the four remaining stars are of the right order, but would point to a distance of 12.5 kpc to the center. Inasmuch as the stars of group 5 are few in number and would be largely affected by any uncertainties in the amount of absorption or the thickness of the stratum, they have not been included in the final results. In general, they indicate that the adopted distance to the center is of the right order.

IX. RESIDUAL RADIAL VELOCITIES

The average residual radial velocity after taking out the effects of solar motion of 20 km/sec and the circular rotation about the center is, for groups 1–4, 10.1, 7.6, 12.4, and 14.0 km/sec, respectively, with a mean of 10.8 km/sec. This includes accidental errors of observation, the effect of errors in apparent magnitude resulting from photometric estimates, and uncertainties in the absorption correction, as well as the component of the peculiar motion of the stars in the line of sight. There is little evidence for group motion among the Cepheids, except, perhaps, for the stars of the Perseus-Cassiopeia region, longitude 80°–120°, which, in general, have large negative residuals.

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TEMPERATURE CLASSIFICATION OF EUROPIUM LINES*

ARTHUR S. KING

ABSTRACT

The paper gives wave-length measures and temperature classifications for 3950 europium lines from λ 2100 to λ 10165. Of these, slightly less than 2200 belong to neutral europium. A very large intensity range is found for both neutral and singly ionized lines. Many of the former are relatively stronger in the furnace than in the arc. The absorption furnace spectrum was used to obtain low-level lines in the ultraviolet to λ 2659. Lines of *Eu* II, selected by comparison of arc and spark spectra, range from low-level furnace lines to those much enhanced in the spark. An ultraviolet spark spectrum, which is absent from the arc, probably belongs to *Eu* III. In addition to arc and furnace intensities, the degree of widening, due to hyperfine structure, of a large proportion of the lines is indicated in Table 2.

Close agreement of lines in the sunspot spectrum with the ultimate lines of *Eu* I indicates the presence of neutral europium in the solar atmosphere. Additional identifications of *Eu* II lines in the sun have been made.

Approximately three-fourths of the lines ascribed by Eder to a suggested unknown substance "eurosamarium" have been identified as belonging to known rare earths, nearly half being lines of europium.

Seventeen bands of $EuCl_3$ appearing in the furnace spectrum from λ 5695 to λ 7450 have their limiting wave lengths given and their distinctive features described.

A previous paper[1] by the writer gave a temperature classification of the lines of europium, together with those of four other rare earths, in the range λλ 3900–4700. The main purpose was to describe lines in the spectral region which at that time was of most astrophysical interest. The present paper covers the spectrum from λ 2100 to λ 10165 for the lines of *Eu* I and *Eu* II down to a fairly low intensity, giving the temperature classification of lines in both groups.

The examination of this spectrum, carried on at intervals during several years, was at first rendered especially difficult by lack of an adequate supply of europium. The earlier spectrograms were made from Urbain preparations, small in amount, and, with the exception of one pure specimen used for checking identifications, mixtures of europium with gadolinium or samarium. When these impure prep-

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington,* No. 608.

[1] *Mt. W. Contr.*, No. 414; *Ap. J.*, **72**, 221, 1930.

arations were used up, some spectral regions were still not photographed under all the desired conditions; and the data in general lacked the fainter lines, especially of *Eu* I, which were found later, when experiments with europium in liberal quantity could be carried out. At this stage, Dr. Herbert N. McCoy, having developed, at his private laboratory in Los Angeles, a method of obtaining very pure europium,[2] generously supplied the writer with all the material needed to do justice to the spectroscopic study. Much better spectrograms were then obtained, not only for the region previously photographed, but also for extensions into the ultraviolet and infrared.

The number of spectrograms made for europium was much larger than for any of the rare earths previously studied, chiefly on account of the great range in line intensity. Lines of enormous strength scattered through the spectrum became overexposed and unfit either for estimates of intensity or for wave-length measurement before the main body of the spectrum was fully developed. Faint lines desirable for the term analysis appeared only on plates so strong as to be useless for the other groups. As separate sets of plates were made for wave-length measures and for intensity estimates, it was necessary to provide for the three groups of lines in each set. Finally, absorption spectra, more effective in bringing out furnace lines in the short wave-length region, supplemented the furnace emission spectra.

EXPERIMENTAL METHOD

The laboratory procedure was, in general, that used in previous studies of rare-earth spectra. The carbon-tube furnace was operated at temperatures of approximately 2000°, 2300°, and 2600° C. The McCoy preparation of europium chloride was used except for regions where the chloride bands were strong, when the oxide or oxalate was substituted. To avoid scattering of the material when first heated, it was placed in a small graphite boat midway in the furnace tube. Frequent recharging was needed, the condition of the vapor being indicated by the color of the image on the spectrograph slit.

For the arc and spark spectra, the electrodes were usually "spectroscopically pure" graphite, charged with the europium compound.

[2] *J. Amer. Chem. Soc.*, **58**, 2279, 1936.

Commercial carbons quite free from rare earths were available, however; and as these gave more steady vaporization, with weaker cyanogen bands than the graphite, they were frequently used for the arc. The spark discharge was given by a 40,000-volt transformer, with large oil-immersed condenser, the electrodes usually being graphite wet with liquid chloride. To eliminate the cyanogen bands, some very useful arc and spark spectrograms were made with pure silver electrodes charged with europium. To obtain a rich arc spectrum giving the fainter lines of *Eu* I, a very vigorous vaporization was required, not merely a coloring of the arc flame. Otherwise, the spectrum consisted chiefly of the low-level lines of the ionized atom.

First- and second-order spectra of the vertical concave-grating spectrograph were used—the second order from λ 2500 to λ 5400. Covering this region in the first order also helped to co-ordinate the line intensities over a long range and to distinguish lines which in the second order might be blended with the ghosts of very strong lines.

Wave-length measurements.—The most extensive list of europium wave lengths previously available is that of Eder,[3] on the international system. While these measures are in general good, considering the difficult structure of europium lines and the quality of the standards then available, a full measurement of the spectrum has been made by the writer, the reductions being carried out by Miss Brayton. The many new lines, the improved standards, and the frequent resolution of close lines, usually blended, fully justified this procedure. Direct measures from iron standards were made as far as possible. Some spectrograms, not taken with iron standards but showing groups of difficult lines of favorable intensity, were measured from europium standards whose wave lengths had been carefully determined.

In spite of all care in measurement, high accuracy is not to be claimed for a large proportion of these wave lengths, since hyperfine structure and very frequent dissymmetries present inherent difficulties. Relatively few europium lines can be classed as sharp. Micrometer settings on a line having hyperfine structure depend on intensity—whether faint, with some components predominating, or so strong as to be of even intensity over its width. Repeat measures of

[3] *Sitzungsberichte Wien Akad.*, II*a*, **126**, 473, 1917.

the same plate gave close agreement, while those on plates of different general intensity showed small wave-length differences for many lines. That this difficulty was also experienced by Eder is evident from the differences found by him, up to 0.04 A, in lines from two samples of europium, presumably treated alike both as to photography and measurement. In consequence, only a small proportion of the wave lengths measured in the present work are given to three decimals. These lines were measured in the second order, were narrow in structure, and gave closely concordant values on two or more plates.

A number of lines of very high intensity (2000 and higher) could not be measured satisfactorily on europium spectrograms. A set of gadolinium plates was available, however, made from material contributed by Dr. McCoy, on which practically the only impurity lines were these strong lines of europium, which, although still not sharp, were almost free from photographic widening. Measures for the triplet of ultimate lines—λλ 4594, 4627, and 4662—were obtained from these plates and serve to correct wrong values which have appeared in former lists. A misprint occurred for one line in Eder's and for another in my previous paper; and my value for λ 4594, measured in the furnace, was affected by a blend with a vanadium line from the graphite tube. In the present work these lines were measured when weak, but clearly defined, on three arc plates, as follows:

4594.028	4627.224	4661.879
.024	.225	.878
.025	.222	.877

Two plates on which the lines were still fainter, but distinct, gave lower values:

4594.018	4627.216	4661.871
.015	.214	.868

The difference of about 0.01 A under these two conditions indicates a complex structure; and such differences, or larger, are found for a large part of the europium lines. The wave lengths 4594.03, 4627.22, and 4661.88 appear to be the best values for these ultimate lines when their structure is clearly developed.

Lines of the important multiplet of *Eu* II from λ 3819 to λ 4522

have each a sharp satellite about 0.1 A to the violet of the main line, which itself is complex. For most of these lines the satellite has been resolved in furnace spectra, and sometimes for the arc. When unresolved, the effect of the satellite is to move the wave length about 0.02 A to the violet of that of the strong component.

Absorption spectrum.—The emission spectrum of the furnace, arising from a thermal radiation, has a limit in the ultraviolet corresponding to that of the continuous spectrum of a black body at the same temperature. For still shorter wave lengths the absorption spectrum is useful and, if lines are present, can be extended into the ultraviolet as far as a source of white light can be made to give a continuous spectrum.

The absorption lines obtained correspond to the temperature of the furnace tube and can be classified accordingly. The method gives lines from the ground level at a temperature sufficient to produce a small amount of the vapor.

By means of the continuous spectrum from a 50-ampere Philips lamp with quartz bulb, europium lines were obtained in absorption as far as λ 2659 for tube temperatures which ceased to show an emission spectrum several hundred angstroms above this limit. In the visible region the absorption spectrum agrees closely with that for the same temperature in emission. Absorption spectrograms were useful, however, in checking those for emission and were extended to λ 5500.

FEATURES OF THE EUROPIUM SPECTRUM

The most distinctive feature of this spectrum as a whole is the great range in line intensity; consistent intensity estimates are thus unusually difficult. Groups of lines having extraordinary strength occur both in the *Eu* I and the *Eu* II spectra. There was no reliable means of co-ordinating their intensities with those of moderately strong lines, and the same difficulty arose in connecting the latter with the many very faint lines appearing only on strong spectrograms; hence the intensities are, to a large degree, relative for the members of each of the three groups.

The widening of lines in the arc spectrum, indicated by the symbols "w_1" to "w_5" after the intensities, appears to be due in part to hyperfine structure and in part to high excitation. The first

cause should give similar widening for a line in arc and furnace, and as a rule this is the case. Instances of widening in the arc, often unsymmetrical, while the furnace line is narrow, may be due to the more intense arc excitation, though a higher resolution would be needed to show what is actually taking place.

Lines relatively much stronger in the furnace than in the arc occur very frequently to the red of λ 4700. These were selected by comparing spectra of the arc and high-temperature furnace, in each of which most of the lines were of approximately the same strength. Some were then stronger in the arc, while a considerable number were distinctly stronger in the furnace. Those of the latter group, when estimated to be fully twice as strong in the furnace as in the arc, have been designated by "A" after the class number. On what would be considered a normally exposed arc spectrogram, many of those were not visible. Falling, for the most part, in classes III A and IV A, and therefore not from the lowest levels, they form a distinctive group.

Lack of exact coincidence between arc and furnace lines of europium is very frequent. Many such cases are due to blends of *Eu* I and *Eu* II in the arc and are so noted in the "Class" column of the table, the furnace wave length being given, in addition to that of the arc blend, when it would add to clearness. Some cases in which no disturbance by a spark line occurred are explained as close pairs, one line of which is faint in the arc but strong in the furnace; others, as a superposition in the arc of a sharp low-temperature line on a wide line of high excitation. In other cases the reason for non-coincidence is not clear. Near λ 4650 the wave lengths of several lines are so different in arc and furnace that the furnace value is given in the table and that of the arc-line maximum in the notes. Several noteworthy lines occur in the range λλ 3539–3577. Their strength in the arc depended to an unusual degree on how the arc was burning, and they were often very faint on spectrograms of high general intensity. When well developed, they showed decided unsymmetrical widening. In the furnace they were sharp, both in emission and absorption, but often not located at the position of the arc-line maximum. The arc wave lengths being highly uncertain, those given are for the furnace lines.

In the ultraviolet the neutral lines of wave length shorter than the limit of the furnace spectrum are necessarily placed in class V, though doubtless a fair proportion of them are from the low levels. In this region, and to some extent also at higher wave lengths, there is frequent masking in the spark by lines of a rich spectrum which is quite absent from the arc and probably belongs to *Eu* III. For lines thus disturbed the class is questioned.

Beginning at λ 2659, the regular temperature classification was carried out, at first with the aid of the absorption spectrum. From λ 2659 to λ 3200, and for some of the fainter lines beyond, the furnace intensities are for the absorption lines given by the tube when heated to approximately 2400° C with white light passing through. These estimates are denoted by "(a)" after the intensity value. The assignment of such lines to classes I, II, and III was based on their relative strength in absorption; and the estimates were correlated, as well as possible, with those of greater wave length, which were for emission lines. Besides selecting the low-level lines of *Eu* I in the short-wave-length region, the absorption furnace gave the group of ground-level lines of *Eu* II[4] beginning at λ 3688. Strong at 2400° C, they were so well defined at 2100° C that they should persist at a still lower temperature. This places them in class II E and shows that an appreciable amount of ionized vapor is present near 2000° C.

As in most spectra, the proportions of neutral and ionized lines change in different spectral regions. From λ 2100 to λ 2800, the arc spectrum shows chiefly *Eu* I lines; and the spark, *Eu* III. *Eu* II lines are greatly in the majority from λ 2800 to λ 3800. Through the violet and blue an approach to equal proportions of *Eu* I and *Eu* II prevails, while in the green and on into the infrared, *Eu* II lines, with the exception of one strong multiplet, are faint and scattered. Spark spectrograms for the selection of *Eu* II lines were not made beyond λ 8700; but the lines of still greater wave length, found in the arc and sometimes in the furnace, fit in nearly all cases into the analysis of *Eu* I being prepared by Russell. An exception is a group of nine strong lines near λ 10000, photographed in the arc spectrum. These lines have been placed by Russell[5] as a multiplet of *Eu* II. As no

[4] Albertson, *Phys. Rev.*, **45**, 499, 1934.

[5] Communication by letter.

linkage with *Eu* II lines of shorter wave length was possible, the intensities given are only relative for the group.

In the selection of *Eu* II lines note was made of those strengthened to an unusual degree in the spark spectrum, a condition indicated by a dagger (†) after the class designation. They are evidently the lines of higher excitation in the *Eu* II spectrum.

IDENTIFICATIONS OF EUROPIUM LINES IN THE SOLAR SPECTRUM

With the exception of two lines of neutral ytterbium, lines of rare earths thus far identified in the solar spectrum have been those of the ionized atom. In the *Revised Rowland* five of the very strong violet lines of *Eu* II are identified in the sun, though questioned, except in one case. The very high intensities of some *Eu* I lines made their solar appearance seem possible, and the lines of both *Eu* I and *Eu* II of intensity 200 and higher were compared with the solar list. While many are masked and others are clearly absent, a considerable number agree closely with faint unidentified solar lines, usually of intensities -2 or -3. Some, however, are *Eu* I lines of class III, and not to be expected in the solar spectrum when several very strong lines of classes I and II are absent. The question therefore rested until the energy-levels of these lines were obtained from unpublished data supplied by Russell and Albertson. The use of these showed the presence of *Eu* I lines, at least in sunspot spectra, and identified some additional lines of *Eu* II.

The presence of neutral europium in the sun should be indicated by the three ultimate lines near λ 4600, but the evidence from the disk spectrum is conflicting. The first, λ 4594.03, is masked in the sun by a wide blend, part of which is vanadium. In the position of the second, λ 4627.22, Rowland gives an unidentified line λ 4627.219, intensity -1N. On strong Mount Wilson solar spectrograms this line could be seen, but the structure is too diffuse for close measurement. For the third line, λ 4661.88, only slightly weaker in the laboratory, nothing is to be seen in the sun.

The sunspot spectrum was next examined, since in general the reduced temperature of the spot intensifies low-level neutral lines. On the Mount Wilson spot spectrograms, taken with compound nicol and quarter-wave plate, lines appeared in close agreement with

λ 4627.22 and λ 4661.88, each with rather wide Zeeman effect. They had been measured by Charlotte E. Moore,[6] without identification, on these plates as λ 4627.24 and λ 4661.92?, each of intensity −1. The uncertainty in the second value presumably arose from the blend of the red Zeeman component with an adjacent iron line.

Two other *Eu* I lines from the ground level (a^8S^o), λ 3111.43 (sun, .425) and λ 6864.54 (sun, .527), each of solar disk intensity −3, show laboratory behavior which might permit them to appear in the sun. The first is stronger in the absorption furnace than any other ultraviolet line in the solar range. The other is the strongest *Eu* I line in the long-wave region and is reversed in the emission furnace. The remaining lines from the lowest level, weaker than the foregoing, are masked or absent in the sun, as are nine strong class II lines from the next level $a^{10}D^o$. Sixteen class III lines between λ 4800 and λ 5350, of moderate strength, show good agreement with solar lines of intensity −2 and −3.[7] They are, however, from the higher levels; and as several lines of similar character are absent from the sun, they cannot be accepted as identifications of the solar lines.

In the *Eu* II spectrum, term values furnished by Dr. Russell allowed the selection, from about thirty lines agreeing closely with solar lines, of those whose levels and intensities might permit their appearance in the sun. It was found that the stronger lines from the a^9S^o levels (EP 0.00 and 0.23, respectively) are present unless masked. Those from the a^9D^o level (EP 1.3) show in the sun only when very strong. The characteristics of these lines are given in Table 1. In cases where a violet component has been resolved, the solar line agrees best with the strong red component.

To summarize, we find, with the aid of the spot spectrum, two of the ultimate lines of *Eu* I in the sun, a third and stronger one being masked. Two others, which seem the next most likely to appear, coincide with faint solar lines and may be present. For *Eu* II, eight low-level lines are definitely present in the sun, and two others probably. Several others are masked, and their presence is uncertain.

[6] *Atomic Lines in the Sunspot Spectrum*, Princeton, 1933.

[7] *Pub. A.S.P.*, **50**, 221, 1938.

THE IDENTIFICATION OF LINES ASCRIBED TO "EUROSAMARIUM"

An attempt has been made to identify, from the lists of rare-earth lines now available, the lines observed by Eder[3] in the spectrum of a europium preparation containing samarium and not found by him in the spectra of purified samples of either element. These lines were provisionally ascribed by Eder to the presence in the mixture of an

TABLE 1

Eu II LINES IN THE SOLAR SPECTRUM

λ	Δλ (Sun-Arc)	Solar Int.	Arc Int.	EP	Remarks
3688.42	0.000	4 (*Ni*)	1500	0.00	Masked
3724.94	+ .011	0Nd	4000	0.00	Present
3819.67	+ .020	1Nd	6000	0.00	Present
3907.10	+ .016	0Nd	3000	0.23	Present
3930.50	+ .015	0	4000	0.23	Present
3971.98	+ .016	0d?	4000	0.23	Present
4129.73	+ .002	1	5000	0.00	Present
4205.05	− .021	1	6000	0.00	Present
4435.58	?	?	3000	0.23	Absent unless masked by 4435.690 *Ca*, int. 4
4522.59	?	?	2000	0.23	Masked between two iron lines
6173.05	+ .021	−3N	2000	1.31	Probably present
6437.64	+ .086	−2N	4000	1.31	Probably present as blend in sun, as the line is strengthened in sunspots
6645.11	+0.026	$\dot{-}$2N	8000	1.37	Present

unknown substance, "eurosamarium." One of several possibilities suggested by him, however, was that they might belong to known rare earths whose spectra had not been sufficiently studied. The list of eurosamarium lines is given by Kayser in *Handbuch der Spectroscopie*, **5**, and again in the Kayser and Konen revision, **7**, Part 1. The stronger lines are found under the symbol "Euros" in Kayser's *Hauptlinien*.

Of the 442 lines in Eder's eurosamarium list, the three strongest agree with moderately strong lines of ionized yttrium, and 204 with europium lines given in the present paper; 91 are in my samarium

list,[8] and 23 in that of neodymium.[9] This leaves 121 lines not identified, of which only 5 are of intensity higher than 1. The reason for these lines appearing under the conditions described by Eder is not obvious, but it may be noted that about 60 per cent of the europium lines occurring in the eurosamarium list are either weak *Eu* II lines or *Eu* I of the type stronger in the furnace than in the arc. In either case they are very sensitive to fluctuations in the arc discharge. This suggests that some peculiarity in the arc combustion, perhaps due to the mixture of the two elements, may have intensified these lines in certain spectrograms. In view of the large proportion now identified, it does not appear necessary to consider that a modified form of either europium or samarium is the origin of the unusual spectrum.

BAND SPECTRUM OF EUROPIUM CHLORIDE

Between λ 5695 and λ 7450 a series of seventeen bands appeared when the chloride was vaporized in the furnace. These appear to be new and were obtained of high intensity only in the furnace. Two systems seem to be present, one degraded toward shorter, and the other toward longer, waves. In individual bands, two or three weaker heads usually show on strong photographs, to the red or violet, as the case may be, of the strongest head. The structure is complex and for some bands consists partly of wide lines and partly of shaded flutings.

As the limits of each band are usually fairly well defined, these have been measured, and also the wave length of the strongest part of the structures, with notes as to the band's appearance. The order of the limiting wave lengths indicates whether the band structure degrades toward violet or toward red. The last four in the following list show red shading.

5719.9 –5695.0	Moderately strong. First three members fainter than strong part beginning λ 5714.4, which is degraded to violet
5826.3 –5808.0	Faint, degraded to violet
5917.2 –5876.6	Five faint members to red. Stronger structure begins at λ 5906.7 and degrades to violet

[8] *Mt. W. Contr.*, No. 523; *Ap. J.*, **82**, 140, 1935.

[9] *Mt. W. Contr.*, No. 470; *Ap. J.*, **78**, 9, 1933.

6003.5 –5933.9	Faint structure at red end. Strong portion begins at λ 5997.1 and degrades slowly to an abrupt violet limit
6087.5?–6046.8	Red limit uncertain on account of following band. Structure similar to preceding
6143.5 –6097.6?	Strength increases from red limit to dense structure at λ 6115, then decreases to uncertain violet limit
6184.7 –6179.1 6211.5 –6205.5	Similar in structure, each band degrades to a diffuse violet limit
6261.4 –6218.0	Begins with three faint flutings at red end, followed by three wide lines, then strong head at λ 6246.8, degrading to violet limit
6367.0 –6314.0?	Strengthens to maximum at λ 6326.4. Violet limit uncertain
6496.8 –6413.0	Two diffuse lines at red end, then strong head begins at λ 6490.8
6592.0 –6508.3	Strong head begins at λ 6586.0. Strong fluted structure from λ 6546.2, degrading to violet
6704.5 –6618.2	Faint. Probably degraded to violet
6718.5 –6843.0	Structure of strong pairs at violet end. Flutings shaded to red begin at λ 6780.5
6868.7 –6949.5	Strongest fluting at λ 6891.2
7103.6 –7247.6	Strong lines at violet end. Strong flutings begin at λ 7180.3
7338.6 –7447.3	Strong flutings begin at λ 7347.6.

EXPLANATION OF TABLE 2

The wave lengths in the first column are for the arc spectrum, unless the structure of a line permitted more accurate measurement in the furnace spectrum. The values are to three decimal places for lines whose intensity and sharpness allowed this precision, to one place only for lines so faint or diffuse that a glass scale served best for their measurement. Two wave lengths are frequently entered for an unresolved arc blend. When this is made up of a neutral and an enhanced line, the wave length of the former, measured in the furnace, is given; and for the *Eu* II line, that of the arc blend, of which the enhanced component usually forms the major part. About forty other lines are such close blends of *Eu* I and *Eu* II that no separate measures were possible. These are given a double class in each case. In connection with the arc intensities, "R" and "r" denote distinct and partial self-reversal, respectively, while "w" with a subscript indicates the degree of widening. Of the furnace intensities,

only that at high temperature is given, the behavior at lower temperatures, including initial appearance and rate of strengthening with temperature, being considered in assigning the class given in the final column. Intensities are questioned when uncertain on account of blends, usually with lines in a band structure. Lines of *Eu* II have "E" after the class number, with a dagger (†) if the strengthening in the spark spectrum is exceptional. Neutral lines with "A" after the class number are relatively much weaker in the arc than in the furnace. An asterisk (*) after the wave length refers to a note at the end of the table.

TABLE 2

TEMPERATURE CLASSIFICATION OF EUROPIUM LINES

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
2109.6	2	....	V	2315.53	2	....	V
2115.5	4	....	V	2318.06	$10w_2$	....	V E
2134.6	2	....	V	2318.77	3	....	V
2145.0	1	....	V	2319.8	2	....	V
2153.0	2	....	V	2321.3	2	....	V E ?
2154.4	1	....	V	2323.5	1	....	V
2157.0	1	....	V	2325.34	6	....	V
2169.9	2	....	V	2325.65	4	....	V E ?
2179.8	3	....	V	2327.7	$2w_3$	....	V
2197.9	2	....	V	2328.68	3	....	V
2202.40	20	....	V	2329.58	10	....	V
2207.48	12	....	V	2331.5	1	....	V
2207.97*	8	....	V E	2332.76	8	....	V E
2210.9	1	....	V	2332.97	8	....	V
2212.62	2	....	V E	2334.37	3	....	V
2215.74	30	....	V	2335.23	5	....	V
2224.19	$15w_2$	....	V E	2336.4	1	....	V
2234.0	2	....	V	2337.99	20	....	V E ?
2237.67*	40	....	V E	2339.1	1	....	V
2246.0	2	....	V	2340.64	20	....	V
2247.2	2	....	V	2341.3	1	....	V
2247.51	5	....	V	2341.98	$2w_2$	....	V
2248.9	2	....	V	2343.0	$1w_2$	....	V
2253.5	$1w_3$	....	V	2344.6	1	....	V
2259.42	4	....	V	2345.00	12	....	V
2262.4	1	....	V	2345.7	1	....	V
2267.3	3	....	V	2347.05*	$50w_4$	....	V
2280.66	4	....	V	2347.98	20	....	V
2280.85	6	....	V	2349.2	$2w_2$	....	V
2281.09	4	....	V	2350.92	8	....	V
2283.6	3	....	V	2351.66	4	....	V
2286.52	6	....	V	2352.3	1	....	V
2291.0	1	....	V	2353.18	2	....	V
2291.82	3	....	V	2354.9	1	....	V
2294.48	15	....	V E	2355.88	2	....	V
2294.65	20	....	V	2357.39	12	....	V
2295.04	3	....	V	2358.32	3	....	V E ?
2297.04	2	....	V	2360.84	10	....	V
2298.78	2	....	V	2361.14	$30w_2$	....	V
2299.8	1	....	V	2361.9	$2w_3$	....	V
2302.30	8	....	V	2365.50	4	....	V
2304.0	1	....	V	2368.7	2	....	V
2304.3	2	....	V	2369.3	1	....	V
2306.48	2	....	V	2371.66	$10w_2$	....	V
2307.2	$4w_3$	....	V E ?	2371.89	10	....	V
2308.59	2	....	V	2372.35	6	....	V E
2309.3	1	....	V	2372.85	$20w_2$	....	V
2311.53	$2w_2$	....	V	2375.1	1	....	V
2313.23	3	....	V	2375.31	$60w_3$	....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
2377.50	8	....	V	2464.4	$1w_2$	....	V
2379.42	$3w_2$	....	V	2465.4	1	....	V
2379.65	$50w_2$	....	V	2465.89*	$10w_4$	....	V
2381.9	1	....	V	2466.8	$1w_2$	....	V
2382.6	1	....	V	2468.8	1	....	V
2384.36	3	....	V E	2471.14	$60w_2$	....	V
2385.30	2	....	V	2472.96	8	....	V
2386.05	$40w_2$	....	V	2474.58	8	....	V
2389.26	8	....	V	2476.13	6	....	V
2390.43	8	....	V E	2479.2	1	....	V
2392.77	3	....	V	2480.74	8	....	V
2396.5	2	....	V E	2480.92	15	....	V
2396.87	4	....	V	2482.23	3	....	V
2397.8	1	....	V E	2483.28	5	....	V E
2398.1	1	....	V	2483.84	8	....	V
2398.916	10	....	V	2484.9	2	....	V
2399.498	20	....	V	2487.0	1	....	V
2403.34	5	....	V	2488.13	$4w_2$	....	V
2403.7	1	....	V	2488.55	3	....	V
2405.28	8	....	V	2488.83	3	....	V E ?
2405.9	1	....	V	2490.46	10	....	V E
2407.492	40	....	V	2492.02	15	....	V
2409.9	$1w_2$	....	V	2492.43	4	....	V E
2412.97	2	....	V	2496.4	1	....	V
2413.33	1	....	V	2496.81	10	....	V E
2414.6	1	....	V	2497.56	3	....	V
2418.49	15	....	V	2499.391	50	....	V
2421.0	1	....	V	2504.0	1	....	V
2421.44	30	....	V	2506.15	5	....	V
2421.57	$20w_2$	....	V	2507.14	3	....	V
2423.65	$10w_2$	....	V	2508.09	4	....	V
2424.81	10	....	V	2510.85	$20w_3$	....	V
2425.08	$8w_1$	....	V	2512.6	1	....	V
2428.2	$1w_2$	....	V	2513.76	5	....	V
2434.43	2	....	V	2514.36	$3w_2$	....	V
2435.86	2	....	V	2515.3	2	....	V
2437.91	8	....	V	2515.78	5	....	V
2439.01	6	....	V	2516.10	4	....	V
2439.4	1	....	V	2519.39	6	....	V
2440.53	8	....	V	2520.64	$4w_2$	....	V
2443.3	1	....	V	2521.2	1	....	V
2444.38	3	....	V	2522.83	2	....	V
2445.31	25	....	V	2524.1	1	....	V
2445.99	5	....	V	2524.28	2	....	V
2446.5	$2w_2$	....	V	2525.97	15	....	V
2450.59	15	....	V	2526.15	12	....	V
2452.08	40	....	V	2527.0	1	....	V
2454.3	$2w_2$	....	V	2527.40	5	....	V
2454.944	60	....	V	2528.4	1	....	V
2460.50	$12w_2$	....	V	2530.35	4	....	V
2461.78	$25w_2$	....	V E	2531.5	1	....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
2531.79...	8	......	V	2602.6....	$3w_3$	......	V
2535.36...	8	......	V E ?	2604.608..	40	......	V
2538.52...	4	......	V E	2605.47...	4	......	V
2542.262..	40	......	V E	2606.1....	1	......	V
2546.0....	1	......	V	2608.2....	2	......	V
2546.66...	5	......	V E ?	2609.8....	1	......	V
2547.243..	15	......	V E	2610.5....	2	......	V
2548.01...	1	......	V	2612.46...	8	......	V
2548.63...	4	......	V E ?	2614.1....	1	......	V
2549.22...	5	......	V	2615.6....	1	......	V
2549.82...	4	......	V	2616.25...	6	......	V
2550.0....	2	......	V	2618.9....	$1w_2$	......	V
2552.01...	15	......	V E ?	2619.27...	10	......	V
2553.3....	1	......	V	2619.6....	1	......	V
2554.50...	4	......	V E	2620.45...	6	......	V
2554.781..	50	......	V E	2621.34...	3	......	V
2557.54...	25	......	V E	2624.01...	6	......	V
2559.18...	80	......	V E	2624.7....	1	......	V
2559.7....	1	......	V	2625.04...	2	......	V E
2560.61...	2	......	V	2625.79...	2	......	V
2563.48...	10	......	V E	2626.33...	8	......	V
2563.6....	1	......	V	2626.776*.	25	......	V E
2564.17...	125	......	V E	2628.3....	1	......	V
2564.55...	10	......	V E	2630.0....	1	......	V
2564.98...	$4w_2$	......	V	2631.23...	15	......	V E
2565.71...	6	......	V E	2631.63...	6	......	V E ?
2568.17...	80	......	V E	2632.5....	3	......	V
2568.53...	20	......	V, V E	2635.50...	60	......	V
2568.7....	1	......	V	2636.4....	1	......	V E ?
2570.2....	$1w_2$	......	V	2637.14...	3	......	V
2572.6....	1	......	V	2637.7....	2	......	V
2574.76...	30	......	V E	2638.77...	400	......	V E
2576.22...	10	......	V	2641.27...	250	......	V E
2577.14...	150	......	V E	2642.3....	$2w_2$	......	V E ?
2577.56...	20	......	V	2643.84...	6	......	V
2580.62...	$3w_3$	......	V	2644.7....	$2w_2$	......	V
2581.2....	1	......	V	2645.3....	$2w_2$	......	V
2581.86...	30	......	V E	2646.5....	1	......	V
2582.88...	4	......	V	2648.53...	$10w_2$	......	V
2585.45...	2	......	V	2653.613..	40	......	V E
2585.76...	12	......	V E ?	2654.4....	1	......	V
2586.84...	3	......	V	2654.70...	2	......	V
2589.07...	$15w_2$	......	V	2657.17...	$10w_2$	......	V
2589.4....	1	......	V	2657.57...	3	......	V
2592.61...	10	......	V	2658.41*..	$20w_2$	......	V E
2593.0....	1	......	V	2659.42...	15	2(a)	III
2596.30...	5	......	V	2662.0....	1	......	V
2597.81...	4	......	V	2663.28...	3	......	V
2597.93...	6	......	V	2664.56...	$20w_3$	......	V
2598.95...	5	......	V E	2665.5....	1	......	V
2600.26...	10	......	V	2667.0....	2	......	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
2668.34...	300	....	V E	2731.37...	20	15(a)	I
2670.0....	1	....	V	2732.61...	18	10(a)	II
2670.85...	15	....	V	2733.01...	$2w_2$	....	V
2671.2....	1	....	V	2735.254..	40	12(a)	II
2671.9....	$2w_2$	....	V	2738.57...	15	6(a)	II
2672.8....	1	....	V	2740.0....	1	....	V
2673.424..	60	....	V E	2740.62...	200	....	V E
2675.45...	2	....	V	2741.6....	1	....	V
2678.29...	200	....	V E	2743.28...	80	15(a)	II
2680.2....	1	....	V	2744.26...	200	....	V E
2682.0....	$2w_4$	....	V	2744.7....	1	....	V
2682.60...	8	6(a)	II	2745.61...	40	10(a)	II
2683.5....	1	....	V	2746.8....	1	....	V
2684.8....	$1w_2$	....	V	2747.286..	100	....	V E
2685.66...	200	....	V E	2747.83...	60	15(a)	I
2687.5....	1	....	V	2749.64...	1	....	V
2688.5....	1	....	V E	2752.17...	150	....	V E
2689.3....	1	....	V	2757.14...	2	....	V
2689.8....	1	....	V	2759.7....	$2w_2$	....	V
2692.03...	250	....	V E	2759.9....	$3w_3$	....	V
2692.74...	5	4(a)	II	2762.3....	1	....	V E
2693.4....	1	....	V	2764.99...	2	....	V E
2695.08...	2	3(a)	II	2765.5....	$1w_2$	....	V
2695.36...	1	....	V	2766.3*...	$1w_3$	....	V E ?
2695.60...	5	....	V E	2766.92...	10	....	V
2697.5....	1	....	V	2770.73...	2	2(a)	II
2698.30...	3	....	V	2770.90...	2	....	V E
2700.51...	$4w_2$	....	V	2771.440..	3	3(a)	II
2701.14...	250	....	V E	2771.75...	1	....	V E
2701.90...	400	....	V E	2772.626..	8	....	V
2702.3....	$1w_2$	....	V	2772.903..	10	10(a)	II
2704.7....	1	....	V	2773.40...	2	....	V
2705.28...	150	....	V E	2776.4....	$1w_2$	....	V
2706.5....	1	....	V	2776.516..	10	20(a)	I
2708.13...	3	....	V	2778.1....	$2w_2$	....	V
2708.9....	1	....	V	2779.83...	$4w_4$	....	V
2709.76...	8	....	V	2780.53...	20	....	V
2709.99...	40	10(a)	II	2781.89...	400	2(a)	IV E
2712.39...	3	....	V	2785.0....	1	....	V
2713.3....	$2w_4$	....	V	2785.61...	4	....	V
2715.02...	3	....	V	2787.21...	$6w_2$	....	V
2716.98...	400	2(a)	IV E	2787.7....	1	....	V
2719.0....	1	....	V	2793.5....	1	....	V
2720.61...	2	....	V	2795.33...	2	....	V
2723.4....	1	....	V	2795.53*	8	....	V
2723.96...	50	10(a)	II	2796.15...	6	....	V
2725.7....	$3w_2$	....	V	2796.71...	1	....	V
2727.78...	800	5(a)	IV E	2797.24...	$3w_2$	....	V
2729.33...	$300w_1$	2(a)	IV E	2797.81...	2	2(a)	II
2729.44...	300	....	V E	2800.04...	5	20(a)	I
2730.93...	5	....	V	2801.1....	1	....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
2802.84	600	10(a)	IV E	2865.7	2	....	V E†
2803.42	3	....	V	2867.18	2	....	V E†
2805.68	4	....	V	2868.30	3	....	V E†
2806.10	2	....	V	2868.87	1	....	V
2806.89	3	....	V	2869.05	3	....	V
2807.20	4	20(a)	I	2870.5	1	....	V E†
2808.1	1	....	V	2871.57	12	....	V E
2810.3	$3w_2$	....	V	2873.85	2	....	V E
2810.71*	15	....	V E ?	2874.86	$4w_2$	....	V E†
2811.75	200	....	V E	2876.06*	60	....	V E
2813.083	40	....	V E	2877.784	15	100(a)	I
2813.94	1200	30(a)	IV E	2877.89	2	....	V E
2814.75	2	....	V E†	2878.25	4	....	V E†
2815.5	2	....	V E†	2878.87	50	80(a)	I
2816.18	500	5(a)	IV E	2879.54	2	....	V E
2817.6*	$2w_3$	....	V E† ?	2880.70	$1w_2$	....	V E
2818.95	2	....	V E†	2883.39	1	....	V E†
2820.0	1	....	V	2884.9	1	....	V
2820.78	800	20(a)	IV E	2886.46	3	....	V
2824.0	1	....	V E†	2886.910	20	....	V E
2825.17	8	....	V	2887.85	60	....	V E
2826.6	$2w_2$	....	V	2889.94	$8w_3$	....	V E†
2827.26	30	....	V	2892.54	200	300(a)	I
2828.72	$500w_2$	....	V E	2893.03	150	300(a)	I
2828.81*	?	....	V E	2893.83*	300	200(a)	I, V E
2829.30	125	....	V E	2897.69	2	....	V E
2833.26	125	....	V E	2899.10	8	....	V
2834.34	2	....	V E†	2902.40	2	....	V
2835.7	1	....	V	2904.03	2	....	V
2838.75	2	....	V E†	2904.22	15	....	V
2840.14*	$4w_2$	....	V E†	2904.96	3	....	V E
2841.36	$2w_2$	....	V E†	2906.0	1	....	V
2841.9	1	....	V E†	2906.4*	$?w_3$	....	V E
2843.96	60	....	V E	2906.68	1000	30(a)	IV E
2844.82	1	....	V E†	2907.84	1	....	V
2845.6	1	....	V E†	2908.99	250	400(a)	I
2847.80	2	....	V E†	2912.33	$20w_2$	....	V
2850.1	1	....	V E†	2914.29	4	....	V E
2850.40	3	....	V E†	2916.89	1	....	V E†
2852.05	15	....	V E	2917.439	30	....	V E
2852.55	8	....	V	2918.03	2	....	V E
2854.49	3	....	V E	2920.47	3	....	V
2855.8	$2w_2$	....	V E	2921.14	$5w_2$	....	V E ?
2856.5	1	....	V	2922.17	4	....	V E†
2857.9	1	....	V E†	2922.56	4	....	V E†
2858.4	1	....	V E†	2923.98	8	....	V E
2859.67	300	....	V E	2925.04	600	5(a)	IV E
2860.5	1	....	V E†	2925.2	$2w_2$	....	V E
2861.3	1	....	V E†	2926.18	10	....	V E
2862.57	$500w_2$	....	V E	2926.77	2	....	V E
2864.42	20	....	V	2928.92	3	....	V E ?

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
2931.52	$6w_2$	....	V E ?	2986.92	12	....	V E
2932.53	12	....	V E†	2989.3	1	....	V E
2933.11	1	....	V	2989.95	4	....	V E†
2938.33	2	....	V E	2990.26	15	....	V E
2939.50	6	....	V E†	2990.68	3	....	V E†
2939.76	10	....	V E	2991.33	300	....	V E
2940.45	8	....	V E	2992.37	3	....	V
2940.82	15	....	V E	2993.87	$3w_3$	....	V E
2944.14	5	....	V E ?	2995.221	50	....	V E
2945.40	$10w_2$	....	V	2996.52	2	....	V E
2946.54	1	....	V E	2997.36	2	....	V E
2947.29	100	....	V E	2997.95	$1w_2$	....	V E
2948.23	4	8(a)	II	2998.14	10	....	V E
		.....	V E	2999.13	1	....	V E
2948.68	6	....	V E†	2999.4	1	....	V E
2949.12	25	....	V E	3000.3	$2w_3$	....	V
2950.82	20	50(a)	I	3001.1	$3w_3$	....	V E
2951.16	4	....	V E	3001.36	$20w_2$	....	V
2952.68*	$600w_3$	....	V E	3002.31	5	....	V E†
2954.82	2	....	V E	3003.4	1	....	V
2956.07	2	....	V	3004.23	6	....	V E†
2956.15	6	....	V E	3004.80	20	....	V E
2956.6	2	....	V E	3005.55	1	....	V E
2957.9	1	....	V E	3006.26	80	....	V E
2958.3	2	....	V E	3008.57	$8w_1$	....	V E
2958.63	$10w_2$	....	V E†	3009.54	$12w_1$	....	V E
2958.91	30	40(a)	I	3010.496	4	....	V E
2958.98	8	....	V E†	3012.385	$40w_1$	....	V E
2959.47	80	....	V E	3015.06	$4w_2$	....	V E
2960.21*	$300w_3$	....	V E	3015.52	2	....	V
2963.76	$4w_2$	....	V E†	3015.869	6	....	V
2964.24	$4w_2$	....	V E†	3017.32	1	....	V
2965.90	2	....	V E†	3017.46	$20w_4$	....	V E
2966.52	10	....	V E	3017.974	12	....	V E
2967.58	5	....	V E†	3018.51	$5w_4$	....	V
2968.68	$2w_2$	....	V E ?	3020.12	$5w_2$	....	V E†
2969.11	2	....	V E†	3022.148	60	....	V
2969.4	1	....	V E	3025.00	4	....	V
2973.30	2	....	V	3025.503	12	....	V E
2973.42	5	....	V E	3028.04	$3w_3$	....	V E†
2974.2	2	....	V E	3029.574	10	....	V
2974.5	$4w_3$	....	V	3029.66	1	....	V
2975.12	5	....	V E	3029.81	$3w_2$	....	V
2976.58*	2	....	V E ?	3031.54	2	....	V
2978.950*	20	....	V E†	3035.38	$10w_2$	....	V E
2979.68	4	....	V	3036.11	$4w_2$	....	V
2982.81	2	....	V E	3036.84	5	....	V
2983.26	$3w_2$	....	V E	3038.07	$2w_2$	....	V
2984.4	$2w_3$	....	V E	3038.8	1	....	V E
2985.29	10	....	V E	3039.41	4	....	V
2986.38	6	....	V E†	3039.55	$2w_3$	....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3039.690	6	....	V	3077.358	200	....	V E
3039.884*	10	....	V ?	3078.27	1	....	V
3040.429	12	....	V E	3078.36	1	....	V E
3040.55	$12w_3$	....	V E†	3078.57	$5w_3$	....	V E
3040.77	$40w_3$	....	V E	3078.86	$3w_2$	....	V
3042.53	$4w_2$	....	V E	3079.058	8	....	V E ?
3045.01	$4w_1$	....	V E	3081.06	$2w_2$	....	V E†
3045.94	$6w_3$	....	V E	3081.80	6	....	V E
3046.13	$2w_2$	....	V E	3082.03	1	....	V E†
3046.58	1	....	V	3082.11	5	20(a)	II
3047.39	5	....	V E	3083.71	$3w_2$	....	V E
3049.01	$15w_3$	....	V E	3084.13	$10w_2$	....	V E†
3050.14	$15w_3$	....	V E	3085.39	$5w_1$	....	V E
3051.34	4	....	V E	3085.47	5	....	V E
3052.66	3	....	V	3085.64	3	....	V E
3053.00	$6w_1$	....	V	3085.70	$6w_1$	6(a)	II
3054.43	$2w_3$	....	V	3085.89	2	....	V E†
3054.94	$600w_3$	....	V E	3087.02	2	....	V
3055.04*	40?	....	V E	3087.31	$2w_4$	....	V E
3055.24	$3w_2$	....	V E	3087.89	1	....	V E
3058.984	100	100(a)	I	3088.18	$15w_2$	....	V E†
3060.50	3	....	V	3088.38	$3w_2$	....	V E
3060.59	4	....	V	3089.07	4	....	V E
3060.81	$4w_2$	....	V E	3089.20	$4w_2$	....	V E
3060.95	$2w_3$	....	V	3089.35	$30w_3$	....	V E
3062.24	$8w_4$	....	V E ?	3089.64	3	....	V E
3062.81	2	....	V E	3090.49	$12w_4$	....	V E ?
3063.10	$3w_3$	....	V	3091.292	10	....	V E
3063.51	$12w_3$	....	V E	3092.34	$12w_3$	....	V E†
3063.76	2	....	V E	3093.61	$5w_1$	....	V E†
3064.06	$4w_3$	....	V E	3094.183	6	....	V E
3065.58	3	....	V E	3094.98	1	....	V E
3066.30	$2w_2$	....	V E†	3095.40	$6w_4$	....	V E
3066.950	40	40(a)	I	3095.95	$5w_3$	....	V E
3067.456	6	....	V E	3096.28	$8w_2$	....	V E
3068.47	1	....	V E	3096.54	4	....	V E
3069.110	$50w_2$	....	V E	3097.11	$8w_2$	....	V E
3069.54	$3w_2$	....	V E†	3097.45	$100w_2$	....	V E
3070.09	$2w_3$	....	V E	3097.55	30?	....	V E
3070.46	$6w_1$	....	V E	3097.67	$4w_1$	....	V E
3071.15	$2w_2$	....	V	3097.88	$8w_2$	....	V E
3071.58	$5w_3$	....	V E	3098.205	30	....	V E†
3072.73	3	....	V E†	3098.91	$2w_2$	....	V E
3072.92	5	....	V	3099.53	$8w_2$	....	V E
3073.85	$6w_2$	....	V E	3100.34	$3w_3$	....	V E
3074.556	6	....	V E ?	3101.53	3	....	V
3075.14	$3w_2$	....	V E†	3101.76	2	....	V E
3075.30	$6w_2$	....	V E	3101.940	8	....	V E
3075.83	$5w_2$	....	V E	3102.94	$4w_1$	....	V E†
3076.01	2	....	V E	3103.56	$4w_1$	....	V E
3076.069	30	....	V E	3105.21	$8w_2$	....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3106.18	$100w_3$	100(a)	I	3140.356	15	....	V E
3107.69	$8w_2$	....	V E†	3141.08	2	....	V E
3107.89	1	....	V E	3144.207	15	....	V E
3108.20	8	....	V E	3144.59	2	....	V
3109.40	$6w_2$	....	V E†	3144.82	$6w_3$	....	V E†
3110.26	6	....	V E	3146.35	4	....	V E
3110.42	3	....	V E	3146.59	$3w_3$	....	V E†
3110.60	1	....	V E†	3146.699	6	....	V E
3111.14	$10w_2$	....	V E	3147.434	20	....	V E
3111.43	500R	400(a)	I	3147.74	$4w_2$	....	V E
3112.25	$8w_1$	....	V E	3149.41	$5w_1$	....	V E
3113.02	$30w_3$	....	V E†	3149.59	3	....	V E
3114.03	$5w_2$	....	V E†	3149.88	$60w_2$	....	V E
3115.44	3	....	V E†	3150.484	15	....	V E
3115.77	5	....	V E ?	3150.93	3	....	V E
3117.00	$2w_2$	....	V E	3151.01	4	....	V
3117.21	2	....	V E	3151.84	6	....	V E
3117.48	$2w_3$	....	V E	3151.98	5	....	V
3117.603	15	....	V E	3153.25	$2w_2$	....	V E†
3117.99	$15w_2$	....	V E†	3153.56	3	....	V E
3119.85	$5w_1$	....	V E	3153.83	$2w_3$	....	V E
3121.77	$6w_2$	....	V E†	3154.69	$8w_2$	....	V E†
3122.483	8	....	V E	3155.13	$3w_4$	....	V E
3122.91	6	....	V E	3156.60	$4w_2$	....	V E
3123.14	$2w_3$	....	V E†	3156.95	$4w_3$	....	V E
3123.42	2	....	V E	3157.313	15	....	V E
3124.19	$12w_1$	....	V E†	3157.67	$3w_2$	....	V E
3124.77	$10w_2$	....	V E†	3158.30	$4w_2$	....	V E
3125.11	20	....	V E	3159.52	2	....	V
3125.22	2	....	V E	3160.33	10	....	V E
3125.64	3	....	V E	3160.63	3	....	V E
3127.28	$2w_3$	....	V E	3162.01	3	....	V
3128.46	$3w_4$	....	V E†	3163.36	3	....	V
3128.63	2	....	V E	3164.77	$12w_3$	....	V E†
3128.90*	8	....	V E ?	3165.14	3	....	V
3129.83	3	....	V E ?	3165.65	$4w_3$	....	V
3130.41	$15w_4$	....	V E†	3166.49	$25w_2$	....	V E†
3130.73	$80w_2$	....	V E	3168.282	$30w_1$	50(a)	I
3131.62	$25w_4$	....	V E†	3169.29	$5w_3$	....	V E†
3131.98	2	....	V E	3169.62	$5w_1$	....	V E
3132.16	$40w_3$	....	V	3170.409	50	....	V E
3132.97	3	....	V E	3170.964	10	....	V E
3133.23	$8w_2$	....	V E	3171.45	$5w_2$	....	V E
3134.695	15	....	V E†	3171.58	$6w_2$	....	V E
3135.20	3	....	V E	3171.942	50	....	V E
3135.27	2	....	V E	3172.89	$4w_3$	....	V E
3136.964	15	....	V E	3173.607	100	....	V E
3138.47	$3w_3$	....	V E	3174.19	5	....	V E
3138.93	3	....	V E	3175.08	3	....	V E
3139.30	$8w_3$	....	V E	3175.80	4	....	V E
3139.83	5	....	V E	3176.60	$8w_2$	....	V E†

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3177.45	5	....	V E	3214.79	2	....	V E
3178.49	$4w_3$	....	V E†	3215.67	2	....	V E
3178.708	$12w_1$	....	V E	3217.467	6	....	V E
3179.23	$4w_3$	....	V E	3217.90	$2w_1$	....	V E
3182.86*	$8w_4$	....	V E	3218.57	6	....	V E
3182.98	$12w_3$	....	V E	3218.64	8	....	V E†
3183.65	3	....	V E	3219.05	$4w_3$	....	V E
3183.77	2	....	V E ?	3219.224	6	....	V E†
3184.229	8	....	V E	3219.86	$4w_3$	....	V E
3185.54	$70w_3$	20(a)	II, V E	3221.694	30	....	V E
3186.44	4	....	V E	3221.93	3	....	V E
3187.03	6	....	V E†	3223.69	$5w_2$	....	V E
3189.45	$3w_2$	....	V E†	3224.19	3	....	V E ?
3190.60	$15w_1$	....	V E†	3224.66	5	....	V E†
3191.40	6	....	V E ?	3226.33	$8w_3$	....	V E†
3193.15	$2w_2$	....	V E†	3226.68	$5w_1$	....	V E†
3193.27	8	....	V E	3227.27	$2w_2$	....	V E
3194.11	2	....	V E†	3228.90	$5w_2$	....	V E†
3194.32	$4w_2$	....	V E	3229.80	$6w_2$	....	V E
3194.59	2	....	V	3230.30	$5w_1$	....	V E†
3195.100	10	....	V E	3230.61	5	5(a)	II
3195.52	4	....	V E	3231.87	$10w_2$	....	V E
3195.76	$2w_2$	....	V E	3232.02	$4w_3$	....	V E†
3196.560	10	....	V E	3232.315	$20w_2$	....	V E†
3197.61	$2w_2$	....	V E	3232.52	4	....	V E
3197.91	$3w_2$	....	V E	3232.82	5	....	V E
3198.33	$2w_2$	....	V E	3233.01	2	....	V E
3198.764	20	....	V E	3233.41	2	....	V
3198.86	$2w_2$	....	V E	3233.88	1	....	V E
3201.33	3	....	V	3234.12	$2w_2$	....	V E
3203.04	4	....	V E	3234.31	$15w_3$	....	V E
3203.65	4	....	V E	3234.89	4	....	V E
3204.45	$5w_2$	....	V E	3235.126	30	30	I
3205.50	$5w_2$	....	V E	3235.81	$4w_2$	....	V E
3206.58	3	....	V E ?	3237.37	$15w_4$	....	V E
3206.74	4	....	V E	3238.82	$5w_2$	....	V E
3207.31	$20w_3$	....	V E†	3239.92	6	....	V E
3208.70	1	....	V E	3240.11	$10w_2$	....	V E
3209.13	$3w_3$	....	V E	3240.68	$20w_3$	....	V E
3210.16	10	....	V E	3240.89	4	....	V E
3210.57	300	60	II	3241.405	50	40	I
3210.93	2	....	V	3244.207	8	....	V E†
3211.48	$4w_2$	....	V E†	3244.47	$12w_3$	....	V E†
3211.62	$4w_3$	....	V E†	3244.630	4	....	V E
3211.90	4	....	V E	3246.032	$20w_1$	25	I
3212.20	6	....	V E†	3246.393	20	....	V E
3212.81	1000R	100	II	3246.47*	$2w_3$	....	V E ?
3213.75*	200	40	II, V E	3246.75	$15w_3$	....	V E†
3213.91	$5w_2$	....	V E†	3247.324	30	....	V E
3214.05	4	....	V E	3247.550*	$40w_1$	50	I
3214.26	1	....	V E	3248.30	$4w_1$	....	V E†

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3250.00...	6	....	V E	3288.519..	10	....	V E
3251.44...	$20w_2$	....	V E†	3290.39...	$2w_2$	....	V E
3254.69...	$4w_2$	....	V E	3291.38...	$6w_3$	....	V E
3254.79...	$4w_2$	....	V E†	3291.63...	3	....	V E
3255.28...	4	....	V E	3291.85...	2	....	V E
3255.43...	$6w_2$	....	V E	3292.12...	$8w_4$	....	V E
3255.74...	$4w_2$	....	V E	3293.00..	3	....	V E
3258.68...	$20w_2$	....	V E†	3294.43...	2	....	V E
3259.38...	3	....	V E	3296.66...	$3w_3$	....	V E
3259.49...	5	....	V E	3296.91...	$2w_3$	....	V E
3260.63...	3	....	V E†	3297.45...	$8w_4$	....	V E
3260.74...	4	....	V E†	3297.59...	3	....	V E
3260.87...	6	....	V E	3298.30...	$25w_4$	....	V E†
3262.50...	10	15	I	3298.81...	10	....	V E
3262.59...	$10w_1$	....	V E†	3298.88...	4	....	V E
3263.00...	$5w_3$	....	V E	3299.14...	10	....	V E
3263.48...	$6w_3$	....	V E	3299.27...	1	....	V
3263.68...	$5w_2$	....	V E	3299.67...	$4w_1$	....	V E
3265.69...	$10w_1$	....	V E	3300.38...	12	....	V E
3266.39*..	200	....	V E	3300.61...	4	....	V E
3267.03...	$5w_2$	....	V E	3300.78...	$12w_3$	....	V E†
3268.58...	$6w_3$	....	V E	3301.25...	$4w_2$	....	V E
3269.39...	$5w_2$	....	V E	3301.568..	$15w_2$	....	V E
3269.65...	3	....	V E	3301.95*..	150	....	V E
3270.02...	2	....	V	3302.38...	4	....	V E
3270.24...	$5w_2$	....	V E	3302.85...	$15w_3$	....	V E†
3271.03...	$6w_3$	....	V E	3302.97...	2	....	V E
3272.49...	$3w_2$	....	V E	3303.164..	6	....	V E
3272.77*..	400	....	V E	3304.19...	$40w_2$	....	V E
3274.29...	$20w_3$	....	V E	3304.497..	50	....	V E
3274.94...	$8w_4$	....	V E	3304.84...	3	....	V E
3275.07...	4	....	V E	3306.055..	5	....	V E†
3275.43...	5	....	V E	3306.44...	$4w_1$	....	V E
3275.51...	4	....	V E	3306.95...	5	....	V E
3277.78*..	600	....	V E	3307.03...	3	....	V E
3278.54...	4	....	V E	3307.34...	$6w_2$	....	V E†
3279.440..	15	....	V E	3308.02*..	200	....	V E
3280.19...	$6w_2$	....	V E	3308.95...	$6w_3$	....	V E†
3281.32...	2	....	V E	3310.38...	$8w_4$	....	V E†
3281.45...	$6w_2$	....	V E†	3310.80...	$10w_2$	2	III, V E
3282.23...	3	....	V E	3312.15...	$10w_3$	....	V E†
3282.51...	$20w_4$	....	V E†	3313.01...	2	....	V E
3283.87...	$10w_2$	....	V E†	3313.33*..	400	....	V E
3284.40...	$4w_2$	....	V E ?	3314.03...	2	....	V E
3284.70...	$2w_2$	....	V E	3314.90...	$4w_1$	....	V E
3284.92...	$2w_3$	....	V E	3315.09...	2	....	V E
3285.11...	$5w_2$	....	V E	3315.56...	$4w_3$	....	V E
3285.88...	$12w_4$	....	V E	3316.47...	$5w_2$	....	V E
3287.03...	3	....	V E	3316.85...	2	....	V E
3287.486..	8	....	V E	3317.35...	8	....	V E
3288.30...	$6w_2$	....	V E†	3319.89*..	80	....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3320.14	$8w_3$	......	V E†	3364.886	5	......	V E
3321.47	$8w_2$	......	V E	3366.09	$8w_2$	......	V E
3321.857	100	......	V E	3366.21	6	......	V E†
3322.263	80	60	I	3367.635	40	......	V E
3322.74	8	......	V E	3369.055	200	......	V E
3324.21	4	......	V E	3370.41	$8w_2$	......	V E
3325.97	$30w_3$	......	V E†	3370.52	$8w_1$	......	V E†
3327.08	$8w_2$	......	V E†	3371.69	$10w_3$	......	V E
3328.05	15	......	V E	3373.22	$25w_3$	......	V E
3328.63	$5w_1$	......	V E	3374.47	$10w_4$	......	V E
3329.54	$8w_3$	......	V E	3376.04	$3w_2$	......	V E
3329.805	12	......	V E	3376.69	$6w_1$	......	V E
3331.21	$15w_2$	......	V E	3377.70	$8w_1$	......	V E
3333.66	$10w_2$	......	V E†	3379.26	$6w_2$	......	V E
3334.137	$6w_1$	......	V E†	3379.65	6	......	V E
3334.33	600r	200	I	3380.25	$100w_1$	......	V E
3335.051	5	......	V E	3381.73	$30w_2$	......	V E†
3335.62	$12w_2$	......	V E	3383.72	$8w_2$	......	V E
3336.51	$15w_2$	......	V E	3386.14	$4w_3$	......	V E
3336.89	$15w_2$	......	V E	3387.41	$20w_1$	......	V E
3337.59	$8w_3$	......	V E	3388.41	$8w_2$	......	V E
3338.49	$30w_3$	......	V E	3389.21	$6w_2$	......	V E
3338.75*	80	......	V E	3390.64	$8w_2$	......	V E
3341.03	8	......	V	3390.783	$80w_1$	......	V E†
3341.12	$6w_1$	......	V E	3391.989	$100w_1$	......	V E
3342.68	$5w_2$	......	V E	3393.26	$15w_2$	......	V E
3345.31	6	......	V E	3393.77	$10w_1$	......	V E
3346.10	$5w_2$	......	V E	3394.064	20	......	V E
3346.630	$20w_1$	......	V E	3395.27	$5w_2$	......	V E
3349.459	8	......	V E	3395.36	$20w_1$	......	V E
3349.7	3	......	V	3396.58	$200w_2$	......	V E
3350.403	$50w_1$	60	I	3399.92	$8w_2$	......	V E
3351.05	8	......	V E	3400.17	3	......	V E
3351.20	$20w_3$	......	V	3402.44	$15w_3$	......	V E†
3351.557	$40w_1$	......	V E	3403.16	12	......	V E
3353.07	5	......	V	3405.40* }	$15w_2$	{ 6	II
3353.705	20	30	I	3405.43 }		{	V E†
3354.38	$30w_2$	......	V E	3405.62	$2w_3$	......	V E
3354.51	$10w_2$	......	V E	3406.14	$25w_4$	......	V E†
3354.60	$10w_2$	......	V E	3407.57	$4w_3$	......	V E†
3355.03	6	......	V E	3409.12	2	......	V E
3355.42	$20w_3$	......	V E	3409.645	15	......	V E
3356.02	$12w_3$	......	V E	3409.95	6	......	V E
3357.107	8	......	V E	3410.47	$8w_4$	......	V E
3357.642	6	......	V E	3410.61	$8w_2$	......	V E†
3361.62	$15w_3$	......	V E†	3412.25	$10w_3$	......	V E†
3362.72	5	......	V	3412.72	$60w_3$	......	V E†
3362.83	$8w_3$	......	V E	3413.20	4	......	V E
3363.35	$8w_3$	......	V E	3414.02	5	......	V E
3364.21	$15w_1$	......	V E	3414.13	$6w_2$	......	V E†
3364.29	3	......	V E	3416.33	$8w_3$	......	V E†

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3416.73	$60w_3$	....	V E†	3457.56	$30w_1$	....	V E
3416.86	$30w_2$	....	V E	3459.36	$10w_3$	....	V E†
3417.42	$10w_3$	....	V E†	3460.281	15	....	V E
3418.91	$15w_3$	....	V E	3461.22	$10w_3$	....	V
3419.845	25	....	V E	3461.38	$80w_1$	....	V E
3421.231	12	....	V E†	3463.031	6	....	V E†
3421.68	$25w_3$	....	V E†	3463.28	$12w_4$	....	V E†
3423.09	$60w_3$	....	V E†	3466.413	40	....	V E†
3424.59	$5w_1$	....	V E†	3466.86	$20w_3$	....	V E†
3425.022	80	....	V E	3467.880	30	40	I
3426.442	20	....	V E	3468.72	$2w_2$	....	V E
3427.045	6	....	V E	3469.28	$30w_3$	....	V E†
3427.757	15	....	V E	3470.25*	10	8	II
3428.03	$5w_3$	....	V E†	3470.6	$2w_2$	1	III
3428.329	5	....	V E	3472.10*	$5w_4$	3	III
3428.76	$15w_3$	....	V E	3472.71*	15	....	V
3428.92	$12w_3$	....	V E†	3472.75*	10	....	V
3429.25*	$15w_2$	....	V E†	3473.60*	$6w_3$	3	III
3429.33*	$12w_2$	....	V E†	3473.86	8	....	V E†
3429.79	$5w_2$	....	V E	3474.50	$15w_3$	....	V E†
3430.38	$15w_2$	....	V E†	3476.604	30	....	V E
3430.89	$10w_2$	....	V E†	3476.98*	25?	....	V E
3432.520	20	30	I	3477.07*	$20?w_3$	1	IV
3434.15	4	....	V E	3477.19*	8?	1	IV
3434.76	$6w_3$	....	V E†	3478.19	5	....	V E ?
3435.05	$40w_3$	....	V E†	3480.405	6	....	V E†
3435.20	$40w_1$	....	V E	3480.50	5	1	IV
3435.72	$30w_2$	....	V E†	3480.837	6	....	V E
3436.034	5	....	V E	3481.62	$30w_4$	....	V E†
3439.59	$10w_1$	....	V E ?	3482.53	$12w_3$	....	V E†
3440.25	2	....	V E	3485.16	$15w_3$	....	V E†
3440.820	$30w_1$	....	V E	3485.43	$25w_2$	....	V E
3440.999	$80w_1$	....	V E	3485.86	$20w_2$	....	V E†
3443.54	$6w_3$	....	V E†	3487.09	$8w_2$	....	V E†
3443.97	4	....	V	3487.28	2	5	II
3445.176	30	....	V E	3488.301	30	....	V E
3445.73	4	....	V E	3489.25	$25w_3$	....	V E†
3445.83	6	....	V E	3490.48	$15w_2$	....	V E†
3446.37	$20w_3$	....	V E†	3491.11	$12w_3$	....	V E†
3448.16	$10w_2$	....	V E†	3493.32	1	2	IV, V E
3448.43	5	....	V E	3493.403	$6w_1$	....	V E
3448.53	$4w_2$	....	V	3495.13	$15w_3$	....	V E†
3451.80	$6w_3$	....	V E	3497.65	5	....	V E
3452.00	$6w_3$	....	V E	3497.84	$10w_3$	....	V E†
3452.25	$15w_2$	....	V E ?	3499.41	$4w_1$	2	III, V E
3453.474	$50w_1$	....	V E†	3501.69	$8w_3$	....	V E
3453.89	4	3	III	3502.49	$8w_1$	....	V E†
3454.146	15	....	V E†	3502.79	$20w_3$	....	V E
3454.76	$40w_4$	1	IV, VE†	3503.22	$20w_2$	3	IV
3457.050*	40	50	I	3503.77	4	....	V E
3457.056		.....	V E	3503.95	$10w_2$	....	V E†

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3504.09...	$8w_2$	....	V E	3542.68...	$5w_3$	....	V E†
3504.44...	$4w_2$	....	V E	3543.11...	6	....	V E†
3505.30...	$20w_3$	....	V E†	3543.85...	$60w_3$	....	V E†
3505.95...	$8w_3$	....	V E†	3544.17...	$20w_2$	....	V E
3506.43...	$4w_2$	....	V E	3544.77...	$12w_3$	....	V E†
3506.598..	$8w_1$	....	V E	3545.14...	$8w_2$	....	V E†
3506.645*.	?	5	IV	3547.10...	$20w_2$	....	V E†
3507.49...	4	....	V E	3548.05...	4	....	V E†
3508.731..	$10w_1$	....	V E ?	3548.49...	$4w_2$	....	V E
3508.852..	$20w_1$	....	V E	3549.6*...	$8w_4$	....	V E†
3511.03...	$60w_2$	....	V E	3549.71...	$20w_3$	....	V E†
3511.163..	10	....	V E†	3551.27...	$8w_1$	....	V E
3511.86...	$10w_3$	....	V E†	3552.516..	100	....	V E
3512.268..	5	....	V E	3553.89...	2	....	V E
3513.326..	10	....	V E	3554.91...	8	3(a)	III
3513.794..	4	....	V E	3555.15...	6	5(a)	III, V E
3514.205..	12	....	V E	3555.39 }	$5w_3$	{ 3(a)	III
3514.48...	$15w_2$	....	V E†	3555.40 }		{	V E†
3518.482..	25	....	V E†	3555.93...	$2w_4$	....	V E†
3520.14...	$8w_3$	....	V E†	3557.75...	$6w_2$	....	V E†
3520.40...	$4w_2$	....	V E†	3558.91...	$4w_2$	....	V E†
3520.91...	$10w_4$	....	V E†	3559.09...	6	?	V ?
3521.09...	100	....	V E	3559.42...	3	....	V E†
3522.37...	$15w_2$	....	V E	3560.59...	$4w_4$	?	V ?
3523.17...	$10w_4$	....	V E†	3562.174..	20	....	V E
3523.49...	$30w_2$	....	V E	3562.72...	$5w_3$	....	V E†
3525.78...	$6w_2$	....	V E†	3563.79...	$3w_3$	....	V
3526.06...	8	....	V	3565.23...	5	....	V E
3526.17...	4	....	V E	3565.82...	6	....	V E†
3526.648..	8	....	V E†	3565.88...	6	....	V E†
3527.87...	$30w_3$	....	V E†	3566.78...	$4w_3$	....	V E
3528.60...	$6w_3$	....	V	3569.11...	$4w_2$	....	V E†
3529.34...	6	....	V E	3570.10...	$40w_1$	....	V E†
3530.36...	$8w_1$	....	V E†	3572.09...	$5w_2$	....	V E†
3531.151..	60	....	V E	3572.58...	$20w_1$	....	V E
3531.79...	$15w_3$	....	V E†	3572.89...	6	....	V E
3532.23*..	25	....	V E	3573.92...	$10w_2$	....	V E†
3532.71...	2	....	V E†	3574.92...	$6w_1$	....	V E†
3533.00...	4	....	V E	3576.20*..	$15w_4$	8(a)	II
3533.12...	4	....	V E†	3576.94*..	$10w_4$	6(a)	II
3534.12...	$20w_1$	....	V E†	3577.15*..	$8w_3$	2(a)	III
3535.88...	2	....	V E†	3578.11...	$2w_1$	....	V E
3537.56...	6	....	V E†	3578.49...	$8w_3$	....	V E
3537.74...	$15w_2$	....	V E†	3579.15...	$4w_1$	....	V E
3538.08...	40	....	V E	3579.33...	$4w_1$	....	V E†
3539.27...	2	2(a)	V E, III	3580.21...	$3w_3$	....	V E
3539.65...	2	3(a)	III	3580.49...	$3w_2$	....	V E
3539.78...	4	2(a)	III	3583.22...	3	....	V E
3541.18...	12	....	V	3583.69...	$2w_2$	....	V E
3541.34...	$20w_3$	....	V E†	3585.84...	$5w_3$	....	V E
3542.152..	80	....	V E	3587.14...	4	....	V E†

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3588.09	$4w_2$	....	V E†	3619.17	$8w_4$	....	V E†
3588.55	$5w_2$	....	V E†	3619.82	$6w_3$	....	V E
3589.270	60	60	I	3619.96	$5w_2$	5	III
3590.146	15	....	V E†	3620.20	$6w_2$	....	V E†
3590.58	3	....	V E†	3620.33	$4w_1$	....	V E
3590.90	2	....	V E	3620.58	$6w_2$	....	V E
3591.312	20	....	V E	3620.89	$30w_2$	....	V E
3591.361	15	....	V E	3621.49	$6w_2$	6	III
3591.79	8	....	V E†	3621.890	$50w_1$	....	V E†
3592.85	$20w_4$	....	V E	3622.48*	10?	3	III
3593.52	2	....	V E	3622.54	150	....	V E†
3596.15	$10w_3$	....	V E†	3623.11	$8w_2$	....	V E†
3596.85	$20w_3$	....	V E†	3623.430	12	....	V E
3598.237	10	....	V E†	3623.65	10	....	V E
3598.57	$8w_1$	....	V E	3623.72	$10w_2$	....	V E†
3600.30	$6w_3$	....	V E†	3624.13	$6w_2$	....	V E
3601.08	$8w_2$	....	V E†	3625.19	$6w_2$	....	V E
3601.72	$8w_1$	....	V E	3627.41	$25w_2$	....	V E†
3602.17	$4w_2$	....	V E	3627.77	10	....	V E
3602.49	$12w_3$	....	V E†	3627.99	$5w_3$	2	III, V E
3603.20*	$200w_2$	....	V E	3629.8	$30w_4$	....	V
3604.67	5	....	V E†	3629.80*	40	....	V E
3605.33	$8w_3$	....	V E†	3630.50	12	....	V E
3605.57	$5w_3$	12	II	3631.792	$15w_1$	....	V E†
3606.17	$4w_3$	....	V E†	3631.97	8	....	V E
3606.39	$8w_3$	....	V E	3632.18	$80w_1$	....	V E
3606.54*	2	5	II, V E	3632.67	4	....	V E
3606.70	80	....	V E	3632.86	$8w_3$	....	V E
3607.28	$8w_3$	1	III	3633.03	2	....	V E
3607.90	4	....	V E	3633.20	4	....	V E
3608.70	$20w_1$	....	V E	3635.85	$20w_2$	....	V E†
3610.50	$8w_3$	....	V E†	3636.718	10	....	V E†
3610.59	4	....	V E	3636.92	$4w_3$	....	V E
3611.01	5	....	V E†	3637.68	$50w_1$	....	V E
3611.357	$25w_1$	....	V E	3638.10	$6w_3$	....	V E†
3611.57	100	1	V E	3638.38	$5w_2$	....	V E†
3611.63*	$10?w_2$	....	V E	3639.02	5	....	V E
3611.94	$6w_3$	....	V E	3639.27	$4w_1$	....	V E†
3612.19	$20w_2$	....	V E†	3640.25	2	1	III
3612.46	$8w_2$	....	V E†	3640.56	3	....	V E
3612.68	4	....	V E	3641.19	$20w_1$	....	V E
3613.77	$6w_2$	....	V E†	3641.27	$20w_1$	....	V
3614.07	$15w_3$	....	V E†	3642.47	$5w_2$	....	V E
3614.26	$8w_2$	....	V E	3643.59	$5w_2$	....	V E
3614.80	$8w_1$	....	V E	3643.96	$8w_2$	....	V E†
3616.152	$100w_2$	....	V E	3644.32	$8w_1$	....	V E†
3616.77	$4w_1$	....	V E	3644.46	12	4	III, V E†
3617.04	$6w_2$	....	V E	3644.972	$10w_1$	....	V E
3617.5	$2w_2$	2	III	3645.18	$30w_2$	....	V E
3618.17	$25w_3$	20	II	3645.43	4	....	V E
3618.47	$8w_3$	....	V E†	3646.65	$30w_1$	....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3646.75	$35w_1$	....	V	3676.87	$25w_2$	....	V E†
3647.02	$12w_2$	....	V E	3678.259	$100w_1$	....	V E
3647.88	$5w_4$	6	III	3678.49*	6?	6	III
3648.26	$15w_3$	....	V E†	3678.64	5	....	V E
3648.86	$2w_3$	2	IV	3679.500	80	....	V E
3649.806	15	....	V E	3680.76	$25w_2$	....	V E†
3650.38	3	....	V E	3681.09	2	....	V E
3650.50	3	....	V E	3681.43	3	....	V E†
3651.09	$15w_4$	5	III	3681.53	$5w_2$	....	V E†
3651.17	$5w_2$	....	V E	3682.23	3	1	III
3652.00	$8w_4$	....	V E†	3682.417	$30w_2$	5	III
3652.14		1	IV	3682.61*	$4w_3$	3	III
3652.60	$6w_1$	....	V E	3683.267	40	....	V E
3654.95	$15w_4$	....	V E†	3683.62*	$6w_3$	4	III
3655.25	8	....	V	3683.84	4	....	V E
3656.19	$20w_3$	10	II	3685.675	6	....	V E†
3657.38	$12w_3$	....	V E†	3686.79	$4w_1$	....	V E
3657.60	4	....	V E	3687.78	80	....	V E†
3658.77	$10w_3$	....	V E	3688.42	$1500w_2$	200	II E
3659.11	$15w_2$	....	V E†	3688.97	4	....	V E
3660.01*	3	4	III	3689.52	$5w_2$	....	V E
3660.577	15	....	V E	3690.47	4	....	V E
3660.629	12	....	V	3691.495	3	....	V
3661.911	4	....	V E	3691.551	3	....	V
3662.33	$20w_3$	....	V E†	3691.96	$6w_3$	....	V E†
3662.50	$25w_3$	....	V E†	3692.39	2	....	V E†
3662.94	$30w_2$	....	V E	3692.65	8	....	V E
3663.41	15	....	V E	3693.12	$5w_3$	....	V E†
3663.47	12	....	V ?	3693.80	$20w_2$	....	V E†
3663.71	$5w_4$	....	V E†	3695.14	3	....	V E†
3664.29	3	....	V E	3695.82	$5w_2$	....	V
3664.92	$3w_1$	....	V E†	3696.1	$4w_3$	....	V
3665.15	$6w_1$	1	III	3696.42	$20w_3$	....	V
3665.88	3	....	V	3697.3	$4w_2$	....	V
3666.27	15	....	V E†	3697.62	$6w_2$	....	V
3666.77	$8w_2$	....	V E†	3697.94	$12w_2$	....	V E†
3668.52	$5w_3$	....	V E†	3699.28	2	1	III
3668.96	$5w_2$	....	V E	3701.12	$5w_2$	....	V E
3669.14	$10w_3$	....	V E	3702.13	$6w_3$	....	V E
3669.78	$20w_4$	....	V E†	3702.39	$6w_1$	....	V E
3670.81	$12w_3$	....	V E	3703.09	$4w_2$	....	V E
3671.72	5	....	V E	3703.56	$25w_2$	....	V E†
3672.18	$6w_2$	....	V E ?	3703.83	$8w_2$	4	III
3673.19	$80w_2$	....	V E†	3703.91	$6w_2$	....	V E
3673.68	2	....	V E	3704.95	6	....	V E
3674.35	3	....	V E	3705.13	3	....	V E†
3674.634	50	....	V E	3706.231	5	....	V E
3675.70	$4w_2$	....	V E	3706.58	$4w_3$	....	V E
3675.81	$6w_1$	....	V E	3706.75	$3w_2$	5	III
3676.15	$1w_3$	....	V E	3707.42	$20w_3$	....	V E†
3676.64	$20w_2$	....	V E	3708.00	3	....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3708.46	$10w_3$	6	II	3738.08	$80w_3$	....	V E†
3709.10	$2w_3$	....	V E†	3738.77	$15w_4$	1	IV
3709.48	$8w_1$	....	V E	3739.47	4	....	V E
3710.282	10	....	V E	3740.25	$20w_1$	....	V E†
3710.870	80	....	V E	3741.31	400	1	IV E
3711.19	$3w_3$	....	V E	3741.62	12	....	V E
3711.65	$8w_3$	....	V E	3742.34	$15w_2$	....	V E†
3712.18	8	....	V E†	3743.556	100	1	IV E
3712.40	8	....	VE	3744.20	$30w_3$	20	II
3712.50	$6w_3$	....	V	3744.54	$20w_2$	....	V E
3713.45	125	....	V E	3746.05	$20w_3$	1	IV ?
3714.904	$100w_1$	....	V E	3746.72	$5w_2$	....	V E†
3715.32	$3w_2$	....	V E	3747.21	$3w_1$	....	V E†
3715.505	3	....	V E	3749.7	5	1?	IV ?
3715.66	4	....	V	3750.65	$2w_2$	....	V E
3716.937	$60w_1$	....	V E†	3751.08	$10w_2$	....	V E
3716.98*	?	4	III	3751.43	$6w_1$	....	V E†
3717.69	$80w_2$	....	V E†	3752.51	5	....	V E
3719.16	$100w_2$	40	II	3752.57	3	....	V
3720.39	$8w_3$	....	V E	3752.83	$15w_2$	....	V E†
3720.72	$10w_3$	....	V E†	3753.05	$30w_3$	....	V E†
3722.00	4	....	V	3753.77	$6w_2$	....	V E†
3722.629	$100w_2$	6	IV	3754.9	2	....	V E
3723.81	6	....	V E†	3756.80	$4w_2$	....	V E†
3724.19	5	....	V E†	3757.42	$15w_2$	....	V E†
3724.94	$4000w_2$	400	II E	3757.639	30	....	V E
3725.785	$5w_1$	4	II	3758.29	$30w_4$	?	V
3726.37	$5w_2$	....	V E†	3758.54	$20w_4$	....	V E
3726.62	5	....	V E†	3760.33	$50w_3$	....	V E†
3726.91	$8w_3$	....	V E†	3760.78	$10w_3$	15	II
3727.33	$4w_3$	....	V E†	3761.12	300	....	V E
3728.21	$8w_3$	6	II	3762.3	$8w_4$	4?	III ?
3729.06	$15w_1$	....	V E	3763.02	$8w_2$	....	V E†
3729.43	6	....	V E	3764.7	5	....	V E†
3729.682	30	....	V E	3765.93	150	....	V E
3729.740	20	....	V E	3766.09	$8w_1$	....	V E†
3730.94	2	....	V E ?	3768.49	$12w_3$	....	V
3731.22	$8w_2$	....	V E	3769.33	$15w_4$	....	V E†
3731.84	$25w_4$	....	V E†	3770.29	8	....	V E
3732.20	$50w_3$	30	II	3770.7	1	....	V E†
3732.73	$8w_2$	....	V E†	3771.147	$25w_2$	....	V E†
3733.65	$25w_2$	....	V E†	3772.74	6	....	V
3734.28	$5w_2$	....	V E	3774.10	$150w_3$	20	III
3734.63	2	....	V E†	3775.47	$4w_2$	....	V E
3734.85	$15w_4$	....	V E†	3775.69	$5w_2$	....	V E†
3735.62	$8w_2$	5	II	3776.22	$15w_2$	10	II
3735.94	20	....	V E ?	3776.51	$5w_1$	....	V E†
3736.06	10	....	V E	3777.2	$2w_4$	....	V
3736.26	2	....	V E	3777.613	$15w_1$	....	V E†
3737.37	2	....	V	3778.33	$1w_1$	....	V E†
3737.62	6	....	V E	3778.65	$4w_1$	?	V ?

TABLE 2—*Continued*

λ	Intensity		Class
	Arc	Furnace	
3778.87	$6w_3$	....	V E
3779.87	$6w_1$	....	V E†
3780.54	10	....	V E†
3781.07	$3w_2$	....	V E†
3781.40	$50w_2$	....	V E†
3784.26	$15w_3$	....	V E†
3785.48	4	....	V E†
3785.82	$15w_2$	....	V E†
3786.32	2	....	V E†
3786.81	$15w_3$	....	V E†
3786.98	$8w_2$	....	V E†
3787.19	$5w_2$	....	V
3787.94	10	....	V
3788.765	$30w_1$	....	V E
3789.17	$10w_2$	....	V E†
3790.70	$3w_2$	....	V E†
3791.50	$30w_1$	....	V E
3791.60	$15w_3$	....	V ?
3793.06	$25w_2$	....	V E
3793.845	5	....	V E†
3794.16	$2w_2$	....	V E
3794.39	$4w_3$	....	V E
3794.776	5	....	V E†
3795.04	20	....	V E†
3796.01	$8w_4$	....	V E
3796.33	$8w_2$	....	V E†
3797.52	$1w_3$	....	V E†
3798.8	1	....	V
3799.009	100	....	V E
3799.492	10	....	V E
3799.66	3	....	V E†
3800.55	$10w_2$	....	V E†
3801.58	$8w_2$	....	V E†
3802.24	$2w_2$	....	V E
3802.64	$6w_3$	2?	III ?
3802.70	$4w_1$	....	V E†
3803.38	$4w_4$	....	V E
3804.27	$15w_2$	....	V E†
3805.81	$5w_1$	....	V E†
3806.76	3	....	V E†
3807.09	1	....	V E†
3807.54	$30w_2$	....	V E†
3810.76	$3?w_2$.	....	V E†
3811.33	$20w_3$	20?	II
3813.07	1	....	V E†
3815.495	$80w_2$	....	V E†
3817.66	8	....	V E†
3817.76	$5w_2$	....	V E†
3819.67	$6000Rw_2$	600	II E
3821.4	2	....	V E
3823.34	$6w_2$	....	V E†
3825.14	$10w_2$	....	V E†
3826.68	$50w_1$	....	V E†
3828.93	$30w_3$	6	III, V E
3830.65	$6w_2$	....	V E
3831.18	$8w_2$	....	V E†
3832.155	$3w_2$	....	V E†
3834.92	3	....	V E†
3838.239	30	....	V E
3841.95	2	....	V E†
3842.354	8	....	V E†
3843.15	50	....	V E
3844.23	$8?w_3$	....	V E†
3846.40	4	....	V E†
3847.845	50	....	V E
3848.20	$8w_2$	....	V E
3848.40	$10w_1$	....	V E†
3849.38	8	....	V E†
3849.62	2	....	V E†
3854.64	$20w_2$	....	V E
3854.812	20	....	V E†
3856.53	$5w_1$	....	V E†
3857.69	5	....	V E†
3859.53	4	....	V E†
3860.728	10	....	V E†
3861.18	$80w_2$	....	V E†
3863.66	10	....	V E
3864.11	$40w_2$	....	V E
3864.87	$2w_2$	....	V E†
3865.29	$15w_1$	....	V E†
3865.57	$150w_2$	40?	III
3866.19	$20w_2$	....	V E†
3869.75	80	20?	III
3872.72	$30w_2$	10?	III
3873.11	$4w_2$	....	V E†
3875.10	$8w_3$	?	V ?
3875.34	$30w_2$	12?	III
3875.95	4	?	V ?
3876.07	2	....	V E
3877.27	$40w_1$	....	V E†
3877.88	10	....	V E†
3879.58	3	....	V E
3880.23	1	....	V E
3881.32	3	....	V E
3881.92	$5w_2$	?	V ?
3883.64	$20w_2$	....	V E†
3884.42 }	$8w_2$	{	V E
3884.46 }		{ 6	IV
3884.75	$100w_2$	50	III
3887.33	$2w_2$	....	V E
3887.818	$4w_2$	....	V E†
3888.684	4	....	V E

TABLE 2—*Continued*

λ	Intensity		Class
	Arc	Furnace	
3888.92	$2w_1$	....	V E
3889.22	$1w_1$	....	V E
3889.52	$6w_2$	2	V E†, IV
3991.26	$2w_3$	....	V E†
3891.49	$8w_1$	4	IV
3892.85	$4w_3$	....	V E
3893.12	$6w_3$	4	IV
3894.09	2	....	V
3894.72	$12w_1$	6	IV
3894.94	$2w_1$	....	V E
3895.11	3	1	IV
3895.49	1	2	IV A
3895.56	$2w_2$	....	V E
3896.45	$1w_3$	....	V
3896.78	$15w_2$	8	II
3897.22	$6w_3$	....	V E†
3897.70	$30w_2$	30	II
3898.18	$10w_2$	10	II
3898.25		.....	V E
3898.48	6	2	V E, IV
3898.75	$30w_2$	30	II
3899.10	1	....	V E
3899.49	$10w_2$	....	V E†
3899.660	6	2	IV
3900.18	$10w_3$	....	V E†
3900.42	$8w_3$	....	V E
3900.51	$40w_1$	40	II
3900.916	$10w_1$	12	II
3901.63	$3w_2$	....	V
3903.233	$20w_2$	20	II
3903.62	$3w_2$	....	V E†
3903.945	$5w_1$	....	V
3904.89	$3w_1$	2	IV
3905.67	$4w_1$	....	V E
3907.10*	$3000rw_2$	150	II E
3909.90	5	4	IV
3910.16	3	3	IV
3911.60	$5w_2$	2	V E, IV
3911.97	$4w_2$	1	IV
3912.42	$3w_2$	....	V E
3913.37	2	....	V E
3913.72	$10w_3$	....	V E
3913.79		3	IV
3914.14	$15w_2$	8	IV
3914.82	$10w_3$	4	V E, IV
3915.24	$15w_1$	....	V E†
3915.62	$25w_1$	10	II
3916.00	50	30	II
3916.82	$20w_2$	10	II
3917.29*	$60w_2$	20	V E, II
3917.70	$10w_1$	....	V E
3917.82	$6w_2$	....	V E
3918.18	4	....	V E†
3918.520	$40w_1$	20	II
3919.09	15	....	V E
3920.097	4	....	V E
3922.17	3	....	V E
3922.526	$3w_1$	....	V E
3922.87	2	....	V E
3923.17	2	....	V
3926.97	$2w_2$	....	V
3927.45	$10w_1$	6	III
3927.95	4	....	V E
3928.87*	$15w_2$	....	V E
3928.98	$8w_3$	....	V E
3929.81	$15w_1$	12	III
3929.91	6	....	V E
3930.42*	$4000rw_2$	20	II E
3930.50*		200	
3932.17	$1w_2$	....	V E†
3934.38	4	....	V E
3935.98	8	....	V E†
3936.643	10	8	III
3937.47	$2w_2$	....	V E
3937.62	$1w_1$	....	V E
3938.248	2	....	V E
3839.19	$8w_1$	....	V E†
3939.44	$2w_1$	....	V E
3939.99	$2w_1$	....	V E
3940.37	$10w_2$	2	I V
3941.49	3	....	V E
3941.56	$20w_3$	....	V E
3942.04	$2w_3$	2	I V
3942.21	$30w_2$	1?	V E, IV?
3942.35	$15w_1$	10	III
3942.94	$8w_1$	....	V E†
3943.08	$40w_1$	....	V E
3943.97*	6	3?	V E, III
3944.59	$6w_1$	....	V E
3945.16	$2w_2$	....	V E
3945.67	$15w_3$	....	V E
3945.72		3	IV
3946.18	$4w_2$	2	IV
3946.6	$1w_2$	....	V E
3947.31	1	....	V E
3947.60	$3w_3$	....	V E
3948.60	$6w_3$	....	V E
3948.79	$2w_3$	....	V E
3949.126	$8w_1$	....	V E
3949.60	$50w_2$	30	II
3949.84	$15w_1$	2	IV, V E
3950.76	$4w_4$	....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3951.33	$2w_2$	......	V E	3986.08	$8w_2$	4	IV
3952.25	$4w_2$	4	IV	3986.60	$40w_1$	30	II
3953.43	$6w_3$	......	V E	3986.92	$4w_2$	......	V E†
3954.25	$8w_2$	3	IV	3987.10	$6w_1$	2	IV
3955.75	$80w_3$	40	II	3987.24	$3w_3$	3	III
3956.013	2	......	V E	3987.90	$30w_4$	20	III
3956.61	$2w_2$	......	V	3988.24	$8w_2$	......	V E†
3957.050	$6w_1$	......	V E	3988.594	5	......	V E†
3957.916	$15w_1$	......	V E	3991.15	3	1	IV
3959.22	$3w_3$	......	V E	3992.362	$8w_1$	6	II
3960.52	$2w_2$	......	V	3993.931	$15w_1$	......	V E
3960.74	$3w_1$	......	V E	3994.68	3	......	V
3961.12	$20w_3$	15	II	3995.07	$4w_2$	1	IV
3961.94	2	2	IV	3995.74	$8w_3$	3	IV
3963.61	$15w_3$	8	II	3995.98	$10w_2$	......	V E
3964.49	$25w_3$	20	II	3996.6	1	......	V E†
3964.90	$60w_2$	......	V E	3998.81	$4w_2$	......	V E
3964.95		10	III	4000.70	$30w_1$	8	III
3965.02	$15w_3$	......	V E	4000.81	$20w_1$	6	III
3966.06	2	......	V E	4001.32	$2w_1$	......	V E
3966.46	5	4	IV	4002.01	$2w_2$	......	V
3966.59	$8w_2$	......	V E†	4002.42	$3w_3$	......	V
3967.18	$25w_3$	20	II	4002.90	$8w_2$	4	IV
3968.88	$3w_1$	......	V E†	4003.71	$12w_1$	......	V E†
3969.22	$15w_2$	15	II	4004.59	$6w_1$	......	V E
3969.90	$10w_4$	6	III	4006.20*	$10w_5$	3	IV
3970.26	1	......	V E†	4007.69	$3w_2$	......	V E
3970.61	4	......	V E	4008.87	$6w_2$	......	V E
3971.10*	$8w_3$	1	V E†, IV	4009.01	$2w_1$	......	V E
3971.89*	$4000rw_2$	20	II E	4009.15	$1w_1$	1	IV
3971.98*		200		4009.42	1	......	V E
3973.07	1	......	V E	4009.55	1	......	V
3973.37	3	......	V E†	4010.176	3	......	V E
3973.86	$5w_1$	......	V E	4010.427	40	20	III
3975.20	$4w_2$	2	IV	4010.815	$2w_1$	......	V
3975.566	5	......	V E	4011.69	100	......	V E
3975.94	$5w_2$	......	V E†	4012.82	$15w_3$	......	V E†
3976.832	15	12	III	4013.58	$5w_4$	2	IV
3977.62	$3w_1$	......	V E†	4014.01	$2w_2$	......	V E
3978.42	$50w_1$	30	II	4014.382	25	12	III
3979.02	$10w_2$	5	IV	4014.65	$12w_1$	4	IV
3979.13	4	......	V E	4014.90	$1w_2$	......	V
3979.19		1	IV	4015.44	$4w_4$	......	V E
3979.634	$8w_1$	......	V E†	4016.694	125	60	II
3980.05	$2w_1$	......	V E	4017.58*	$100w_2$	1	IV E
3981.11	$2w_3$	......	V E	4017.72	$20w_2$	......	V E
3981.316	$5w_1$	......	V E	4018.39	$6w_3$	......	V E†
3981.45	$3w_2$	......	V E	4019.72	$4w_1$	......	V
3983.00	$6w_2$	4	IV	4021.012	$5w_1$	......	V
3985.18	$10w_2$	6	IV	4021.84	2	1	IV
3985.60	$2w_2$	......	V E	4022.91	$6w_3$	4	IV

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4023.70	$4w_4$	2	IV	4067.41	3	2	IV
4024.34	$4w_1$	....	V E	4068.34	$4w_3$	....	V E
4025.445	$8w_1$	4	IV	4068.96	$30w_2$	15	III
4025.95	$25w_1$	6	IV	4070.52	$5w_2$	3	III
4026.51	$50w_1$	15	III	4071.20	$60w_2$	20	III
4027.28	$2w_2$	....	V	4071.34	$10w_2$	5	IV
4028.52	$10w_1$	3	IV	4071.38		....	V E
4028.62	$40w_1$	10	III	4073.52	$5w_4$	1	IV
4029.577	$4w_1$	....	V E	4073.76	8	6	III
4029.99	$150w_1$	60	II	4074.48	$3w_4$	....	V
4030.21	$10w_1$	5	IV	4075.62	1	....	V
4030.66	$5w_1$	4	IV	4075.92	$2w_2$	1	IV
4031.35	4	....	V E	4076.83	2	2	IV
4032.67	$2w_2$	1	IV	4076.95	$4w_2$	....	V E
4033.71	$10w_1$	4	IV	4077.15	$2w_2$	....	V E
4034.102	$4w_1$	....	V E	4078.24	40	30	II
4034.51	1	1	IV	4080.48	3	1	IV
4036.15	$50w_3$	50	II	4080.77	4	....	V E
4036.55	$20w_2$	6	IV	4081.044	5	....	V E
4036.90	2	....	V E	4081.87	2	....	V E
4036.99	1	2	IV A	4084.71	$1w_2$	....	V E
4037.149	$5w_2$	....	V E	4084.88	$6w_1$	3	IV
4037.66	$10w_3$	4	IV	4085.038	$4w_1$	....	V E
4038.37	$10w_1$	5	IV	4085.38	$40w_2$	....	V E
4039.19	$200w_2$	100	II	4085.50	$15w_3$	2	IV
4040.48	$50w_3$	40	II	4086.423	$8w_1$	....	V E ?
4041.94	$15w_1$	2	IV	4087.09	$3w_1$	....	V E
4042.018		....	V E	4087.60	$4w_1$	1	IV
4043.97	$20w_3$	20	II	4087.86	$8w_1$	4	IV
4044.36	2	2	IV	4088.80	1	....	V
4047.74	$6w_2$	5	III	4089.75	3	....	V E
4049.83	$4w_3$	3	IV	4090.20	$4w_3$	....	V
4050.43	$4w_2$	....	V E	4090.77	$3w_1$	....	V
4052.08	$8w_2$	4	IV	4092.96	$3w_1$	....	V E
4053.087	$10w_1$	6	IV	4094.30	$2w_2$	....	V E
4055.26	$4w_2$	2	IV	4094.9	$2w_3$	....	V
4057.91	1	....	V E	4095.93	$5w_2$	1	IV
4058.45	$12w_2$	10	IV	4096.804	$40w_1$	....	V E
4059.03	$10w_1$	3	IV	4099.03	$3w_3$	....	V E
4059.37	$15w_2$	....	V E	4099.71	$3w_2$	....	V E
4060.00	$20w_3$	6	IV	4100.34	4	2	IV
4060.28	$15w_2$	10	III	4100.71	$4w_3$	....	V E
4061.566	$10w_1$	....	V E	4101.43	$5w_2$	1	IV
4062.15	$15w_2$	....	V E	4102.702	$25w_1$	10	III
4062.31	2	....	V E	4103.87	$20w_3$	8	III
4062.65	$15w_3$	....	V E	4105.84	$6w_2$	....	V E
4062.79	2	....	V E	4106.22	3	....	V E
4062.81	4	2	IV	4106.345	6	3	IV
4065.422	20	20	III	4106.60	$3w_2$	....	V E
4066.05	$4w_2$	....	V E	4106.77	60	2	IV
4067.132	3	1	IV, V E	4106.88		40	II

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4107.90...	$10w_3$	....	V E	4150.306..	8	....	V E
4108.57...	$2w_1$	....	V E	4151.19...	12	....	V E
4108.97...	2	....	V E	4151.52...	$20w_2$	....	V E
4109.93...	$4w_3$	....	V E	4151.64...	$8w_3$	....	V E
4110.07...	1	....	V E	4151.81...	2	2	IV
4111.07...	$5w_2$	....	V E	4152.14...	10	6	IV
4112.04...	$30w_2$	....	V E	4153.44...	8	....	V E
4112.17...	$20w_3$	....	V E	4154.50...	6	1	IV
4113.03...	$2w_3$	....	V	4154.94...	2	....	V
4115.65...	2	2	IV	4157.724..	$40w_1$	25	III
4117.016..	15	5	IV	4158.78...	$8w_3$	8	IV
4117.72...	$2w_1$	....	V	4159.24...	$5w_2$	....	V E
4119.30...	$15w_1$	....	V E	4160.27...	3	3	IV
4120.27...	$2w_2$	....	V E	4160.475..	12	....	V E
4120.77...	$6w_1$	....	V E	4161.31...	10	....	V
4121.81...	$2w_1$	....	V	4161.72...	$6w_2$	3	IV
4122.10...	$2w_2$	2	IV	4162.14...	8	....	V E
4122.78...	$5w_1$	....	V	4163.06...	$4w_3$	....	V
4122.94...	$5w_3$	....	V E	4166.05...	2	....	V
4123.85...	2	2	IV	4166.34*..	$3w_1$	1	V E, IV
4124.54...	$10w_2$	....	V E	4166.86...	1	....	V E
4124.892..	12	....	V E	4166.94...	$5w_2$	4	IV
4125.53...	$20w_3$	8	IV	4169.35...	5	....	V E
4127.28...	60	40	II	4170.0....	$2w_3$	....	V E
4128.10...	$8w_1$	10	IV	4171.06...	3	....	V
4128.80...	?	1	IV	4171.70...	4	2	IV
4129.64*	$5000rw_2$	15	II E	4172.05...	$6w_3$	....	V
4129.73*		250		4172.80...	$30w_3$	....	V E
4131.05...	$4w_2$	....	V E	4173.33...	2	....	V E
4133.10...	$6w_2$	....	V E	4173.60...	2	....	V E
4134.955..	5	....	V E	4173.72...	$3w_1$	6	V E, IV A
4136.19...	$6w_1$	3	IV	4175.16...	$12w_2$	....	V E
4136.59...	$20w_1$	....	V E	4176.62...	$8w_2$	....	V E
4137.07...	$50w_1$	30	II	4176.73...	$25w_2$	20	III
4138.30...	$2w_1$	....	V E	4177.37...	5	....	V E
4138.51...	$8w_2$	6	IV	4177.57..	$15w_2$	....	V E
4139.22...	$10w_3$	15	IV	4177.59..		2	IV
4139.67...	$15w_1$	....	V E	4178.33...	6	6	IV
4139.97..	$8w_2$	3	IV	4179.37...	4	....	V E
4140.02..		1	V E	4179.88...	8	....	V E
4141.02...	25	....	V E	4180.86...	$2w_3$	2	IV
4141.14...	2	2	IV	4181.77...	1	3	IV A
4141.72...	$40w_2$	....	V E	4182.22...	80	60	II
4142.98...	$8w_2$	4	IV	4183.17...	2	....	V E
4144.51...	$8w_1$	....	V E	4183.78...	4	....	V E
4145.233..	$8w_1$	....	V E	4184.98...	$10w_3$	6	IV, V E
4146.32...	$4w_1$	....	V E	4186.42...	1	....	V E
4147.22...	$12w_2$	....	V E	4187.96...	3	....	V E
4147.81...	$6w_2$	....	V	4189.751..	5	....	V E†
4148.40...	$8w_2$	....	V E	4192.62...	$12w_3$	8	V E, IV
4149.33...	$12w_3$	2	IV	4194.49...	$20w_3$	20	III

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4195.36	$10w_1$	....	V E	4238.34	$4w_2$	....	V
4196.18	$15w_2$	....	V E	4238.689	$20w_2$	....	V E
4198.57	1	1	IV	4240.12	6	6	IV
4202.69*	$50w_4$	60	II	4240.21	4	....	V E
4204.48*	?	6	IV	4240.38	5	....	V E
4204.91 }	$6000rw_2$	{ 15 }	II E	4240.83	$6w_1$	....	V E
4205.05 }		{ 300 }		4241.60	$10w_3$	....	V E
4205.57	$5w_1$	....	V E	4242.48	3	....	V E
4208.17	$5w_2$	....	V E	4244.41	6	....	V E
4208.92	5	....	V	4244.74	$50w_1$	50	II
4209.15	$15w_2$	40	III A	4245.33	8	5	V
4211.275	10	....	V E	4245.46	10	....	V E
4213.48	4	....	V E	4245.85	$3w_1$	....	V E
4213.59	3	....	V E	4246.13	$12w_3$	15	III
4213.86	$8w_2$	10	IV	4246.90	$2w_2$	....	V
4217.27	1	....	V E	4247.06	$25w_3$	20	III, V E
4217.70 }	$10w_2$	{ 5	IV	4247.73	6	12	IV A
4217.75 }		{	V E	4247.88	6	....	V E
4218.00	$4w_1$	1	IV	4249.40	$20w_3$	15	IV
4218.25	2	....	V	4250.33	2	....	V E
4218.45	$6w_3$	....	V E	4251.07	1	....	V
4219.03	10	....	V E	4251.24	1	1	IV
4220.670	$15w_1$	8	IV	4251.70	2	....	V E
4221.075	$25w_1$	....	V E	4253.805	$20w_1$	....	V E
4222.31	$25w_1$	25	III	4253.93*	?	4	IV
4223.876	15	....	V E	4255.25	$12w_3$	15	III
4224.89	$4w_1$	3	IV	4255.95	$8w_1$	10	III
4225.19	2	1	IV	4256.4	1	....	V
4225.68	8	....	V E	4256.69	$2w_2$	....	V E
4226.87	$4w_2$	2	V E, IV	4257.08	$4w_1$	....	V E
4227.40	6	....	V E	4257.85	$4w_1$	....	V E
4227.58	$5w_2$	5	IV	4258.07	$30w_3$	30	III
4227.68	$5w_2$	....	V	4258.19	$8w_1$	....	V E
4228.04*	$3w_3$	1	IV, V E	4258.50	8	....	V E
4229.33	$12w_2$	2	IV, V E	4259.22	$3w_3$	....	V E
4229.520	5	....	V E	4259.99	$2w_2$	....	V E
4230.10	$2w_3$	....	V	4260.23	1	....	V E
4230.63	$12w_3$	6	V E, III	4260.52	$5w_1$	....	V
4231.09	$2w_1$	....	V E	4260.98	$5w_1$	....	V E
4232.19	2	....	V E	4261.16	$3w_1$	....	V E
4232.45	$12w_3$	....	V E	4261.79	$12w_2$	20	III
4233.60	$8w_3$	12	IV	4262.17	$6w_1$	10	III
4234.094	8	....	V E	4262.95	$2w_2$	....	V E
4234.37	$10w_3$	15	III	4263.80	$5w_3$	2	IV, V E
4235.02	$6w_3$	8	IV	4264.70	$3w_2$	3	IV
4235.723	12	....	V E	4264.91	3	....	V E
4235.90	$5w_3$	3	IV	4265.81	4	....	V E
4236.224	$8w_1$	....	V E	4266.38	$4w_2$	6	V E ?, IV
4237.51	$40w_1$	....	V E	4266.76	$8w_2$	8	IV
4237.75	2	....	V	4267.16	1	....	V E
4237.93	6	....	V	4267.44	$3w_2$	....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4267.85	$10w_3$	6	IV	4300.84	$5w_1$	....	V E
4268.44	3	....	V E	4301.58	$6?w_3$	....	V E
4269.33	$4w_3$	....	V	4302.51	10?	6	IV
4269.50	$8w_1$	....	V	4303.43	2	....	V E
4270.244	10	....	V E	4304.32	3	....	V E
4270.50	$12w_2$	6	V E, IV	4306.38	4	....	V E
4271.65	$3w_1$	....	V E	4306.95	$2w_3$	....	V E
4272.11	4	....	V E	4308.00	1?	3	IV A
4272.39	$2w_2$	....	V E	4308.83	3	....	V E
4272.76	$3w_2$	....	V E	4310.19	$4w_1$	1	IV
4273.06	$4w_1$	....	V E	4310.60	$2w_2$	....	V E
4273.60	$3w_2$	2	IV	4311.02	$5w_2$	....	V E
4274.86	$5w_3$	....	V E	4311.28	$3w_3$	....	V E
4275.37	$5w_2$	....	V E	4313.45	$12w_1$	....	V
4275.91	$10w_1$	....	V	4313.85	5	....	V E
4276.20	$30w_2$	20	III, V E	4314.3	$3w_2$	1	IV
4277.66	$2w_3$	....	V E	4315.05	$8w_3$	4	IV
4277.92	1	....	V E	4316.7	1	1	IV
4278.67	1	....	V E	4317.40*	$10w_5$	15	III
4278.97	2	....	V E	4317.67	$8w_1$	....	V E
4279.25	$8w_2$	10	III	4318.90	3	....	V
4279.62	$10w_3$	10	IV	4320.16	$2w_1$	....	V E
4280.05	4	....	V	4320.98	2	....	V E
4280.36	$8w_2$	....	V E	4321.29	$2w_2$	....	V
4280.68	1	....	V	4321.67	3	....	V E
4281.08	$5w_3$	6	IV	4321.87	$4w_2$	....	V E
4281.920	8	....	V E	4322.57	$100w_2$	50	III
4282.45	$6w_4$	5	IV	4324.31	$4w_1$	....	V E
4283.02	2	2	IV	4325.53	$30w_3$	20	III
4283.873	4	....	V E	4326.13	$4w_1$	....	V E
4284.33	$2w_2$	....	V	4326.44	$8w_4$	3	IV
4284.66	$20w_2$	25	III	4329.36	$200w_2$	150	III
4285.34	4	....	V E	4329.97	$200w_2$	150	III
4285.72	$10w_2$	10	III	4330.61	$40w_3$	....	V E
4286.70	4	....	V E	4331.175	100	50	III
4286.92	2	....	V E	4332.40	$2w_2$	....	V E
4287.27	2	....	V	4332.85	$3w_1$	....	V E
4287.44	$20w_2$	12	III	4333.74	$6w_1$	....	V
4287.81	$3w_3$	2	IV	4334.16	$6w_1$	....	V E
4288.60	$2w_2$	....	V E	4334.75	$12w_2$	....	V E
4291.95	$5w_2$	....	V E	4335.45	$4w_2$	....	V E
4292.44	$6w_2$	4	IV, V E	4336.44	6	....	V E
4292.97	$15w_3$	8	IV	4336.71	$8w_2$	3	III
4293.87	$25w_1$	20	III	4337.68	$200w_1$	100	III
4294.54	$3w_2$	....	V E	4338.46	$5w_2$	3	IV
4294.70	3	....	V E	4339.93	$3w_2$	....	V E
4295.44	$15w_2$	....	V E	4340.48	10	....	V E
4297.43	$25w_1$	10	III	4340.70	$15w_2$	....	V E
4297.81	$3w_2$	2	IV	4341.34	2	....	V E
4298.07	$6w_3$	3	IV	4342.55	$4w_2$	3	IV
4298.73	$300w_1$	150	III	4343.25	$30w_2$	25	III

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4345.91	100w_2	60	III	4385.78	3	....	V E
4346.82	4w_1	....	V E	4387.88	250	125	III
4347.26	5w_2	3	IV	4388.38	1	....	V E
4348.13	4w_2	....	V	4389.07	4	....	V E
4349.25	2w_2	....	V	4389.2	2w_2	....	V
4349.49	2	....	V E ?	4390.36	3w_2	....	V E
4349.72	25w_3	20	IV	4391.19	12w_2	1	IV
4349.97	3	....	V E	4391.37	10w_1	....	V E
4350.13	12w_3	10	IV	4394.00	1	....	V
4350.42	2	....	V E	4396.44	2w_1	....	V E
4351.261	4w_1	....	V E	4397.70	8	....	V E
4352.24	6w_2	....	V E	4397.96	8w_3	3	IV
4352.94	5w_1	....	V E	4399.32	15w_2	....	V E
4353.51	2	....	V E	4399.60	2w_2	....	V
4354.47*	?	4	IV A	4401.71	4w_3	....	V E
4354.80	150w_1	80	III	4402.26	2	....	V E
4355.09	300	....	V E	4402.89	2	....	V E
4357.76	5	....	V E	4403.15	6	....	V E
4359.88	1w_2	....	V E	4405.15*	20w_2	4	IV
4360.11	1w_2	....	V E	4405.27		....	V E
4361.21	1	....	V E	4406.79	20w_3	1	IV
4361.57	8	....	V E	4407.07	15w_3	....	V E
4362.25	4w_3	2	IV	4409.07	1w_1	....	V E
4362.43	2	....	V E	4409.65	8w_2	....	V
4365.18	2w_2	....	V E	4410.47	1	....	V E
4366.51	6w_3	3	IV	4410.63	4w_1	3	IV
4367.54	3	....	V E	4411.1	2w_3	....	V
4367.89	2	....	V E	4412.03	8w_2	5	IV
4368.42	8w_3	....	V E	4412.38	4	....	V E
4368.52		3	IV	4412.98	2w_3	....	V E
4369.47	40w_3	15	III, V E	4413.51	12w_1	5	IV
4370.34	20w_2	....	V E	4414.2	1	....	V
4370.47	80w_2	60	III	4414.64	6	....	V E
4371.45	3w_2	....	V	4416.72	3w_1	....	V
4372.20	8w_2	....	V E	4417.25	80w_2	60	III
4373.45	3w_1	....	V E	4417.55	5w_3	6	IV
4374.68	1	....	V E	4419.66	8w_2	....	V E
4375.12	5	....	V E	4421.95	1	....	V E
4375.31	1w_2	....	V E	4422.57	1w_2	....	V E
4376.16	2	....	V	4422.96	3w_2	3	IV
4376.42	3w_1	....	V E	4423.35	4w_3	1	IV
4376.62	3	....	V E	4424.23	1w_1	....	V E
4377.33	2w_1	....	V	4425.17	1w_3	....	V
4378.27	1	....	V E	4426.42	5w_2	....	V E
4379.81	5w_2	....	V E	4426.62	1	....	V E
4380.16	4w_1	2	IV	4426.94	5w_2	4	IV
4380.98	2	....	V E	4429.76	15	....	V E
4382.05	4w_3	....	V E	4430.80	10w_3	5	IV
4383.17*	200w_1	3?	IV ? E	4433.15	3w_2	....	V E
4385.51	2w_2	....	V E	4433.28	8w_2	....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4434.81	$20w_1$	....	V E	4492.39	$4w_3$	....	V
4435.46*	$3000w_2$	15	II E	4494.34	4	....	V
4435.58*		150		4495.05	$15w_2$	....	V E
4436.59	$1w_1$	....	V E	4495.98	2	....	V E
4436.99	$3w_1$	....	V	4497.45	$4w_1$	2	V E, IV
4437.96	4	....	V E	4500.27	$3w_1$	....	V E
4440.04	$6w_1$	2	IV	4502.10	$2w_2$	....	V E
4441.17	2	....	V E	4503.46	$3w_1$	....	V
4441.47	$15w_4$	....	V E	4504.52	$4w_3$	....	V E
4442.42	3	....	V E	4504.98	3	....	V E
4444.26	$4w_1$	....	V E	4505.25	$8w_1$	1	IV
4446.71	$8w_2$	....	V	4505.73	2	....	V E
4449.13	$12w_2$	2	IV	4507.43	$6w_1$	2	IV
4451.63	2	....	V E	4508.66	$10w_1$	....	V
4451.97	$6w_3$	4	IV	4509.04	$4w_1$	2	IV
4453.08	1	....	V E	4510.07	$1w_2$	....	V E
4456.07	$4w_2$	....	V	4511.53	$3w_3$	2	V E, IV
4456.98	$5w_2$	3	IV	4512.24*	$15w_1$	5	IV
4460.88	$2w_2$	....	V E	4512.62	$2w_1$	....	V E
4461.546	2	....	V E	4513.20	$20w_2$	10	III
4462.14	$5w_3$	....	V E	4514.06	$15w_1$	4	IV
4463.83	$3w_2$	....	V E	4514.29	$1w_2$	....	V E
4464.563	40	30	III	4514.44	$2w_2$	....	V E
4464.97	200	....	V E	4514.75	1	....	V
4466.01	$3w_1$	....	V E	4515.49	$2w_2$	....	V
4466.34	$5w_1$	4	IV	4516.94	$4w_1$	....	V E
4467.22	4	3	IV	4517.36	$6w_1$	....	V E
4468.03	$15w_4$	6	IV	4517.76	$20w_2$	6	IV
4469.64	$6w_2$	3	IV, V E	4518.70	$8w_3$	....	V E
4469.91	2	....	V E	4519.54	4	....	V E
4471.64	4	....	V E	4519.79	3	1	IV
4471.99	$50w_1$	40	III	4520.99	$5w_1$	....	V
4472.34	$6w_2$	....	V E	4522.46*	$2000w_2$	10	II E
4472.87	1	....	V E	4522.59*		100	
4474.10	$6w_1$	4	IV	4522.91*	15	20	III
4474.59	$3w_1$	1	IV	4524.49	$12w_2$	8	IV
4475.78	$8w_3$	4	IV	4526.08	$6w_1$	....	V
4476.89	1	....	V E	4526.69	60	30	III
4477.17	$15w_1$	2	IV	4527.01	$3w_1$	1	IV
4478.4	$3w_4$	1	IV	4527.74	2	....	V
4480.11	$10w_2$	....	V	4533.08	2	....	V E
4484.07	$2w_2$	....	V E	4533.63	5	....	V E
4484.67	$8w_2$	....	V	4535.59	$200w_1$	100	III
4485.15	100	....	V E	4538.05	$20w_3$	20	III
4485.52	$4w_2$	....	V E	4538.55	2	....	V E
4487.79	1	....	V E	4539.24	$12w_1$	....	V E
4488.28	$15w_1$	....	V E	4539.69	$3w_2$	....	V E
4488.92	$2w_2$	....	V E	4540.59	$4w_3$	2	IV
4489.26	2	....	V E	4541.95	4	....	V
4490.18	$1w_1$	....	V E	4543.18	$10w_3$	6	IV
4490.59	2	....	V E	4543.80	$6w_1$	....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4544.74	$4w_2$	......	V E	4594.03	10000R	6000R	I
4545.45	$3w_2$	......	V	4597.34	$40w_1$	30	III
4547.22	$3w_2$	......	V E	4599.19	$6w_1$	......	V
4547.70	$4w_2$	......	V	4599.4	$1w_1$	......	V
4548.79	1	......	V E	4601.18	$12w_1$	......	V
4549.52	6	......	V E	4602.63	$15w_2$	8	IV
4550.55	$8w_3$	4	IV	4604.82	6	1	IV
4550.94	$6w_1$	......	V	4605.85	8	1	IV
4551.2	$5w_2$	......	V	4608.18	$2w_2$	2	IV
4551.7	$1w_2$	......	V	4609.14	$1w_2$	......	V
4552.14	$5w_2$	......	V E	4610.8	1	......	V
4552.28	$6w_2$	......	V E	4611.51	$50w_3$	40	III
4553.21	$3w_2$	2	IV	4611.9	1—	1?	IV ?
4555.39	4	......	V E	4612.43	2	......	V E
4555.59	6	......	V E	4614.63	6	......	V E
4555.72	$6w_2$	4	III	4616.49	$30w_2$	25	III
4556.98	4	......	V	4620.2	1	......	V
4558.12	$1w_2$	......	V	4620.32	4	......	V
4562.18	1	......	V E	4621.34	$15w_2$	5	IV
4562.68	$10w_1$	3	IV	4621.69	2	......	V
4562.96	$1w_1$	......	V	4623.39	$8w_3$	3	IV
4564.53	$15w_2$	5	IV	4625.30	$50w_1$	25	III
4564.93	2	......	V E†	4626.1*	$6w_3$	—?	V ?
4565.42	$4w_1$	......	V	4627.22	8000R	5000R	I
4565.57	5	......	V E	4629.82	$15w_2$	6	IV
4566.33	$3w_2$	......	V E	4632.56	$3w_1$	......	V
4567.68	$1w_1$	......	V E ?	4633.07	$8w_3$	......	V
4568.90	$6w_4$	2	IV	4633.68	$6w_3$	......	V
4569.04	$6w_1$	1	IV	4634.72	$4w_2$	2	IV
4570.0	2	......	V	4635.39	6	......	V
4570.52*	$3w_2$	2?	IV ?	4637.49	$2w_1$	1	IV
4571.2	$2w_2$	......	V	4637.74	$2w_2$	......	V E
4571.9	$1w_1$	......	V	4639.40	4	......	V
4572.47	$3w_2$	2	IV	4639.75	4	1	IV
4573.66	$4w_3$	......	V E	4641.41	20	......	V
4574.18	10	......	V	4642.26	4	3	IV
4575.0	$2w_3$	......	V E	4642.50*	$15w_3$	12	IV
4575.22	$15w_1$	......	V	4644.23	50	......	V
4575.79	20	......	V	4645.73*	$8w_3$	2	IV
4576.35	$12w_3$	4	V E, IV	4646.25	$3w_2$	......	V
4576.93	$10w_2$	......	V	4646.56	2	......	V
4577.92	$10w_3$	5	III	4647.1	1—	......	V
4579.77	$3w_1$	......	V	4647.24	1	......	V
4580.23	$5w_2$	......	V E	4647.41*	$15w_2$	8	IV
4580.75	$6w_1$	3	IV	4648.4	1—	......	V
4581.62	5	......	V E	4649.06	$8w_2$	10	III
4585.68	8	......	V E	4650.48	50	40	III
4586.38	$30w_2$	20	III	4651.13	$2w_1$	......	V E
4588.96	$8w_1$	......	V	4651.545	20	......	V
4591.06	8?	......	V E ?	4652.30	$6w_4$	3	IV
4592.43	$4w_1$	......	V	4652.44		......	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4653.30*	$20w_4$	15	IV	4716.29	$2w_2$	....	V E
4653.86*	$6w_3$	5	IV	4717.22	$40w_1$	40	III
4656.73	60	25	III	4718.61	$40w_2$	40	III
4658.63	15	....	V E	4720.21	$6w_1$	8	IV
4660.36	100	50	III	4720.54	$8w_2$	15	III A
4661.01	$15w_2$	8	IV	4723.30	1	....	V
4661.46	$10w_1$	6	IV	4723.90	15	15	III
4661.88	7000R	4000R	I	4724.08	20	20	III
4665.07	20	....	V	4724.90	$3w_3$	....	V
4665.96	1	....	V	4725.69	6	....	V E
4666.59	$5w_3$	....	V	4726.8	$1w_3$	....	V
4667.41*	3	....	V E ?	4727.47	$6w_1$	10	IV
4668.13	$3w_3$	....	V	4728.13	30	30	III
4671.166	25	....	V	4730.70	$4w_1$	—?	V ?
4671.382	10	....	V	4731.82	$3w_1$	6	IV A
4672.85	6	....	V	4734.11	$2w_5$	....	V
4675.49	$20w_1$	15	III	4735.87	$2w_3$	—?	V ?
4679.48	$4w_2$	4	IV	4736.58	40	40	III
4680.1	$1w_1$	1	IV	4739.16	50	50	III
4681.054	15	....	V	4739.94	1	....	V
4681.53	$10w_3$	10	III	4740.50	200	100	III
4682.1	1—	....	V	4741.76	$8w_2$	12	IV
4682.74	1	....	V	4743.65	$1w_1$	....	V
4684.78	$4w_3$	2	IV	4745.66	$1w_2$	....	V E
4685.25	$40w_1$	30	III	4747.6	$1w_3$	....	V
4685.71	$3w_2$	2	IV	4748.5	$1w_2$	....	V
4686.66	$2w_1$	1	IV	4749.64	4	....	V
4686.85	$3w_1$	3	IV	4750.08	$2w_2$	3	IV
4688.24	200	80	III	4751.37	4	....	V
4688.51	$3w_1$	....	V E	4752.42	$2w_1$	3	IV
4689.74	$4w_2$	8	III A	4752.7	$1w_2$	....	V
4690.29	$3w_2$	....	V	4753.71	2	....	V E
4691.30	3	....	V	4754.05	2	....	V
4692.64	$40w_2$	40	III	4755.93	$40w_1$	50	III
4695.35	4	....	V E	4758.74	$40w_3$	30	III
4696.11	1	....	V	4762.39	$2w_2$	....	V
4697.59	8	8	III	4762.92	40	40	III
4698.12	150	60	III	4763.24	$10w_1$	10	IV
4699.42	$5w_2$	5	IV	4763.97	$125w_2$	80	III
4700.42	$3w_2$	5	IV	4765.16	4	5	IV
4702.623	10	....	V	4765.60	$3w_3$	5	IV
4703.36	3	....	V	4766.65	4	6	IV
4703.92	6	5	III	4768.28	3	5	IV
4704.59	$20w_2$	15	III	4768.77	$1w_3$	....	V
4705.99	$3w_3$	3?	IV ?	4769.61	10	15	III
4708.9	$1w_3$	....	V	4770.78	$150w_1$	100	III
4709.81	$20w_2$	15	III	4771.72	$3w_3$	....	V
4712.12	$3w_1$	....	V E	4772.65	$3w_3$	....	V
4712.42	3	2	IV	4773.01	$2w_2$	....	V
4713.04*	1	....	V	4775.41	1—	....	V
4713.59	300	80	III	4775.78	1	....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4776.16...	1	....	V	4825.63...	40	30	III
4776.51...	1	....	V E	4827.95...	4	6	IV
4777.16...	$6w_2$	6	IV	4829.30...	200	80	III
4777.70...	$200w_2$	60	III	4829.86...	20	20	III
4778.64...	100	60	III	4830.33...	250	80	III
4779.34...	$1w_2$	2	IV A	4832.68...	6	12	IV A
4779.70...	4	8	IV A	4833.91...	$5w_2$	....	V
4781.32...	50	40	III	4834.61...	$1w_1$	....	V E
4782.00...	$1w_2$	....	V	4835.61...	$1w_2$	....	V
4783.44...	1	....	V	4837.0....	$4w_5$	2	IV
4783.64...	1	....	V E	4838.22...	3	1	V E, IV
4784.01...	40	40	III	4838.8....	1	....	V
4786.60...	$1w_3$	....	V	4838.92...	$20w_1$	8	IV
4787.61...	4	....	V E	4839.05...	$15w_1$	6	IV
4787.98...	$4w_2$	10	IV A	4839.58...	2	5	IV A
4789.62...	$2w_4$	....	V	4840.47...	150	60	III
4790.6....	1 —	....	V	4841.14...	1	3	IV A
4791.15...	$5w_3$	6	IV	4843.36...	30	40	III
4791.84...	$10w_3$	20	III A	4844.31...	25	30	III
4792.58...	300	150	III	4845.62...	$2w_1$	....	V E
4795.89...	$3w_2$	4	IV	4848.70...	$2w_3$	2	IV
4797.33...	1	....	V	4849.64...	$300w_2$	200	III
4797.9....	50?w_3 }	60	{ III	4851.24...	6	8	IV
4798.06...	60 }		{ III	4851.87...	$3w_2$	3	IV
4798.92...	15	15	IV	4852.03...	5	5	IV
4799.38...	12	20	III	4852.65...	$1w_1$	....	V E
4800.79...	$15w_2$	10	III	4856.17...	1	....	V
4801.2....	1 —	....	V	4856.78...	$3w_2$	8	IV A
4804.08...	100	40	III	4857.95...	1	....	V
4805.18...	5	....	V E	4859.50...	5	....	V E
4805.46...	4	4	IV	4860.29...	1	1	IV
4806.94...	$10w_3$	6	IV	4860.86...	$12w_2$	15	IV
4808.63...	2	....	V	4861.16...	1	3	IV A
4809.29...	200	150	III	4863.12...	2	6	IV A
4810.78...	1	....	V	4866.40...	4	12	III A
4811.74...	1	....	V	4867.62...	600	300	III
4812.07...	1 —	....	V	4870.89...	$1w_2$	2	IV A
4813.55...	8	15	IV A	4873.54...	$1w_2$	....	V
4814.49...	4	....	V E	4878.19...	$2w_2$	....	V
4815.21...	$1w_2$	....	V	4879.17...	$6w_2$	15	III A
4819.54...	$5w_2$	1	IV	4879.47...	$4w_1$	4	IV
4819.88...	$15w_1$	15	IV	4883.05...	$1w_3$	1	IV
4820.47...	$50w_1$	25	IV	4884.05...	150	150	III
4820.80...	$4w_2$	15	III A	4885.10...	$3w_1$	....	V E
4821.43...	1	....	V	4887.45...	$1w_2$	4	IV A
4822.20...	$2w_1$	4	IV A	4891.02...	1	1	IV
4823.25...	1	....	V	4891.55...	3	3	IV
4823.51...	1	....	V	4893.5....	1 —	....	V
4823.79...	2	....	V E	4894.68...	$150w_1$	150	III
4824.26...	4	....	V E	4896.20...	1	....	V
4825.40...	$10w_1$	10	IV	4898.39...	$1w_3$	....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4900.49...	3	....	V	5035.44...	20w_2	15	IV
4900.86...	600	200	III	5037.76...	1	....	V E
4902.66...	1w_1	2	IV A	5041.73...	1w_2	....	V
4907.18...	1500	600	III	5044.82...	1−	....	V
4909.49...	3	....	V E	5045.34...	10w_2	30?	IV A
4910.85...	1w_1	....	V E	5046.29...	1	3	IV A
4911.40...	1800	800	III	5048.18...	1−	....	V E
4917.50...	5	6	IV	5048.99...	1	....	V
4919.34...	1	4	IV A	5049.78...	1w_2	2	IV A
4922.25...	8	15	III A	5052.11...	1w_2	....	V E
4924.6 }	80	{15	IV	5052.61...	4w_2	15?	IV A
4924.73 }..		{15	III	5056.02...	10	30?	III A
4927.42...	1−	....	V	5057.50...	15w_1	15	III
4928.02...	80	30	III	5058.71...	2w_2	4	IV A
4929.06...	1	6	IV A	5058.96...	1	1	IV
4932.83...	125w_1	50	III	5060.00...	5w_1	25	III A
4937.62...	1	....	V	5060.45...	1	....	V
4938.31...	300w_1	80	III	5061.81...	1−	....	V E
4944.57...	1w_2	....	V	5063.74...	200w_1	100	III
4947.39...	200	60	III	5064.56...	1	....	V E
4950.12...	3w_2	....	V E	5065.72...	3	3	IV
4951.32...	1	4	IV A	5066.92...	1w_3	....	V E
4952.8....	1−	....	V	5067.95...	400	300	III
4953.52...	300	125	III	5069.26...	2	2	IV
4958.00...	2	....	V E	5070.04...	1	5?	IV A ?
4960.21...	400	200	III	5070.30...	8w_2	6	III
4961.40...	3w_3	....	V E	5074.44...	1−	....	V E
4962.55...	500	250	III	5074.60...	2w_4	....	V
4964.06...	1−	....	V E	5075.2....	1	2	IV A
4968.73...	150w_1	100	III	5076.01...	1	1	IV
4975.19...	1−	2	IV A	5077.41...	30	20	III
4975.76...	300	150	III	5078.05...	15w_2	20	III
4976.44...	6w_1	....	V E	5079.25...	1w_1	1	IV
4984.02...	12w_1	30	III A	5079.97...	5	15?	IV A
4986.79...	60w_1	80	III	5083.07...	1	....	V E
4991.89...	5	....	V E	5083.81...	1w_2	....	V
4992.73...	1	4	IV A	5085.62...	30w_2	20	III
4995.61...	6	....	V E	5087.18...	4w_1	6	IV
4996.91...	1w_2	....	V E	5089.10...	250w_1	50	III
5001.85...	1w_1	....	V	5091.39...	3w_3	6	IV A
5002.71...	1w_3	1	IV	5092.30...	3w_2	10?	III A
5013.17...	1500	300	III	5092.69...	600w_3	200	III
5015.64...	5w_1	15	IV A	5094.44...	3	....	V E
5017.67...	1	6	IV A	5095.0....	1w_1	....	V
5018.59...	2w_1	....	V	5096.44...	300w_1	50	III
5022.91...	2000	400	III	5098.55...	40	20?	III
5029.4....	100?w_2	50	III	5098.73...	300w_2	100	III
5029.54...	600?	300	III	5101.27...	6	6?	IV
5032.42...	3	3	IV	5102.43...	12w_1	15	IV
5033.55...	500	100	III	5103.65...	1	?	V ?
5034.17...	1	....	V	5106.13...	1w_2	....	V

TABLE 2—*Continued*

λ	Intensity		Class
	Arc	Furnace	
5107.74...	$2w_2$	....	V
5110.03...	2	3	IV
5110.99...	$30w_2$	15	IV
5112.85...	$6w_2$	2?	IV ?
5113.0*...	$5w_1$	6	IV
5114.37...	800	400	II
5115.16...	$1w_2$	....	V
5115.74...	$4w_1$	?	IV ?
5118.15...	$1w_1$	....	V
5118.88...	$2w_2$	4	IV A
5119.47...	$20w_2$	20	III
5121.22...	1−	....	V
5122.25...	1	2	IV A
5122.85...	1	....	V
5124.77...	300	150	III
5126.21...	2	....	V E
5126.60...	$5w_1$	8?	IV
5127.93...	$25w_3$	20	III
5129.10...	1200	500	II
5130.08...	$200w_1$	100	III
5130.47...	$3w_3$	?	V ?
5130.83...	3	3	IV
5131.38...	2	....	V E
5132.42...	$10w_3$	20?	IV A ?
5133.52...	1500	800	II
5135.44...	$8w_2$	10	IV
5135.91...	$1w_2$	....	V
5137.52...	4	10?	IV A ?
5138.51...	$3w_1$	3?	IV
5141.06...	$40w_1$	30?	III
5142.87...	$1w_2$	....	V
5145.70...	$2w_2$	2	IV
5146.04...	$3w_2$	10?	IV A ?
5146.40...	$8w_2$	15	III, V E
5146.72...	$3w_1$	3?	IV ?
5147.80...	$30w_2$	30?	III
5148.41...	$8w_3$	20?	III A
5149.30...	$10w_4$	15?	III
5150.80...	$150w_2$	50?	III
5152.26...	1	....	V
5153.20...	$2w_2$	....	V
5155.42...	$125w_3$	100?	III
5156.41...	30	15?	III
5157.22...	$1w_1$	1	IV
5158.48...	$1w_2$	....	V E
5160.07...	2000	1000	II
5160.39...	$6w_2$	?	IV ?
5162.39...	$3w_1$	3?	IV ?
5163.03...	$1w_2$	....	V
5163.81...	$3w_1$	3?	IV ?
5164.53...	1	−?	V ?
5165.1....	$1w_2$	−?	V ?
5166.70...	1200	600	II
5167.20...	$40w_2$	50	III
5168.17*..	1?	4	IV A
5168.22...	$4w_2$	....	V E
5168.55...	$2w_1$	2	IV
5169.32...	$40w_2$	40	III
5169.75...	$20w_1$	20	IV
5170.50...	$20w_1$	15	IV
5172.39...	1	4	IV A
5174.02...	$12w_1$	12	IV
5174.91...	30	30	III
5175.20...	1	2	IV A
5176.42...	$6w_3$	20	III A
5177.17...	$2w_2$	2	IV
5178.01...	$25w_3$	50	III A
5178.69...	$50w_1$	100	III A
5181.03...	$12w_1$	12	IV
5182.14...	1	1	IV
5183.2*...	$1w_2$	....	V E
5183.56...	$4w_2$	4	IV
5184.30...	2	6	IV A
5188.59...	$10w_1$	10	III
5189.88*..	$10w_3$	10	IV
5193.74...	150	100	III
5197.00...	1	....	V E
5197.32...	$1w_2$	....	V
5198.22...	2	2	IV
5199.27...	4	4	IV
5199.85...	$800w_1$	400	III
5200.96...	400	200	III
5202.58...	1	1	IV
5206.44...	$60w_1$	60	III
5207.88...	$20w_1$	40	III A
5209.77...	1	....	V E
5213.36...	300	250	III
5215.10...	2000	1000	II
5217.01...	200	100	III
5219.22...	$10w_1$	10	III
5219.42...	$4w_1$	4	IV
5222.2....	1	....	V E
5222.28...	2	6	IV A
5223.09...	$20w_2$	40	III A
5223.49...	$1000w_2$	500	II
5224.41...	$1w_1$	5	IV A
5224.68...	$3w_3$	10	III A
5227.3....	1	1	IV
5232.89...	1	3	IV A
5233.90...	50	40	III
5236.13...	30	10	III
5238.47...	1	....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
5239.24	150w_2	150	III	5298.10	40w_2	80	III A
5239.82	2	8	III A	5299.14	1w_3	4	IV A
5240.43	1	3	IV A	5299.63	1	4	IV A
5242.71	40	20	III	5300.11	1	....	V
5243.79	1w_2	....	V	5301.7	1w_3	....	V
5245.55	6w_2	20	III A	5302.72	80w_2	80	III
5246.48	1–	....	V E	5303.85	300w_1	150	III
5248.65	150	30	III	5305.50	5w_1	5	IV
5249.17	150w_2	150	III	5307.00	1–	....	V
5250.13	1–	....	V E	5310.01	3w_2	20	III A
5250.38	2	....	V E	5311.50	1	....	V
5251.86	1–	....	V E	5312.22	5w_2	30	III A
5252.86	2w_2	4	IV A	5315.60	1–	....	V
5253.38	2w_2	....	V	5316.94	20	20	IV
5255.32	1	2	IV A	5318.65	1	....	V
5256.08	30	20	III	5319.46	1w_2	....	V E
5256.79	1–	....	V	5323.02	6w_2	40	III A
5257.44	1	1	IV	5326.2	1	....	V
5258.70	1–	....	V E	5327.3	1w_2	1?	IV ?
5259.86	2w_3	....	V E	5328.79	1–	....	V E
5260.92	2w_2	3	IV	5329.31	2	....	V
5262.25	2w_3	1	IV	5329.89	1w_1	3	IV A
5263.03	50	30	III	5333.28	1	....	V
5264.22	1	....	V	5334.09	1	....	V E
5265.22	2	2	IV	5335.64	1	1	IV
5265.56	2	....	V	5336.97	2w_2	6	IV A
5266.40	1200w_2	800	II	5338.30	8	50	III A
5268.64*	2w_2	2	IV	5341.30	1w_1	4	IV A
5271.47*	5w_2?	5	IV	5341.91	12	10	IV
5271.96	3000	500	III	5343.79	3	3	IV
5272.48	500w_1	300	II	5344.39	1w_2	....	V E
5273.53	1	....	V E	5346.22	1	1	IV
5274.39	8w_1	20	III A	5348.18	1w_1	1	IV
5275.05	15	15	III	5350.14	5?	10?	IV A
5275.66	50	12	III	5350.41	80	40	III
5277.05	2w_2	6	IV A	5350.83	2	....	V
5278.17	20w_1	20	III	5351.69	300	150	III
5278.96	2w_3	1	IV	5352.84	100	50	III
5280.65	25w_2	25	III	5353.84	1	3	IV A
5282.82	1000	300	III	5355.10	300	150	III
5283.31	1–	....	V E	5355.73	10w_2	....	V E
5285.47	40w_1	40	III	5356.73	60	30	III
5285.73	60	40	III	5357.61	1200	1000	II
5287.25	150	150	III	5357.8*	?	50?	III A
5289.25	300w_1	100	III	5360.1	1–	....	V
5291.26	200	60	III	5360.83	250	150	III
5292.54	1w_3	3	IV A	5361.61	500	250	III
5293.68	200w_1	80	III	5362.31	1	....	V
5294.64 }	700w_1	{ 300	III	5364.2	1–	1	IV A
5294.7 }		{ 50?	IV	5364.62	8	8	IV
5295.58	2w_1	2	IV, V E	5368.08	2	2	IV

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
5368.78...	$1w_2$	....	V	5486.70...	$1w_3$	....	V
5371.80...	2	5	IV A	5488.653..	800	600	II
5372.35...	1−	....	V E	5490.03...	3	6	IV A
5374.23...	1−	....	V E	5492.22...	1−	2	IV A
5375.04...	$8w_1$	....	V E	5495.200..	250	200	II
5376.939..	300	150	III	5495.80...	10	20	III A
5384.24...	$1w_2$	1	IV	5496.77...	1	1	IV
5386.19...	$1w_1$	....	V	5497.95...	15	40	III A
5391.00...	3	3	IV	5500.48...	20	40	III A
5392.94...	250	150	III	5500.83...	$100w_1$	100	III
5393.47...	2	2	IV	5502.05...	1	1	IV
5396.01...	$3w_1$	5	IV	5502.30...	2	2	IV
5397.35...	3	....	V E	5504.93...	$3w_1$	15	III A
5399.68...	$3w_2$	10	IV A	5510.52...	$600w_1$	500	II
5402.77...	1200	1000	II	5511.09...	20	20	III
5405.33...	125	80	III	5511.77...	4	4	IV
5406.61...	1−	....	V E	5514.24...	$2w_2$	4	IV A
5407.42*..	$8w_4$	20	III A	5514.92...	$1w_3$	3	IV A
5411.864..	100	60	III	5516.81...	1	1	IV
5412.52...	$8w_3$	20	III A	5517.96...	$2w_2$	2	IV
5413.80...	$15w_3$	40	III A	5519.62...	$3w_1$	6	IV A
5416.27...	$3w_1$	10	IV A	5519.73*..	1−	....	V E
5419.05...	1	2	IV A	5520.45...	1	1	IV
5421.074..	200	150	III	5521.2....	$1w_4$	1	IV
5426.8*...	100?	30?	III	5522.10...	2	1	IV
5426.943..	400	250	III	5522.38...	1	1	IV
5431.55...	$1w_2$	1	IV	5524.44...	1	2	IV A
5436.22...	$2w_3$	2	IV	5525.1....	$1w_3$	....	V
5437.36...	$1w_1$	....	V E	5526.627..	125	125	III
5440.99...	1−	....	V E	5533.25...	80	80	III
5441.63...	$2w_3$	....	V	5536.10...	4	8	III A
5443.564..	250	200	III	5536.83...	$2w_2$	3	IV
5446.55...	1	1	IV	5538.02...	$2w_4$	2	IV
5447.13...	8	10	IV	5539.24...	1	1	IV
5448.20...	1	....	V	5540.74...	2	....	V
5451.51...	1500	1200	II	5541.60...	20	15	IV
5452.94...	1200	1000	II	5542.54...	100	60	III
5457.62...	40	30	III	5547.44...	1200	1000	II
5458.15...	1	1	IV	5549.8....	$1w_2$	....	V
5459.40...	1	....	V	5550.37...	1	....	V
5465.00...	$1w_3$	1	IV	5562.8....	$1w_2$	1	IV
5465.87...	1	....	V	5566.41...	4	4	IV
5467.05...	$20w_2$	40	III A	5566.89...	8	8	IV
5470.81...	1−	....	V E	5570.33...	1000	800	II
5472.324..	600	500	II	5572.65...	$4w_1$	8	IV A
5477.56...	1−	3	IV A	5573.52...	$2w_1$	3	IV
5481.78*..	$3w_4$	6	IV A	5577.14...	1500	1200	II
5482.59...	1−	2	IV A	5578.8....	1−	....	V
5483.52...	1	1	IV	5579.63...	$600w_2$	400	III
5484.40...	$8w_3$	15	III A	5580.03...	800	600	II
5485.50...	15	20	IV	5581.8....	$1w_2$	....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
5584.52	1	....	V E	5684.240	80	50	III
5586.24	800	600	II	5688.38	$20w_3$	40	III A
5586.83	600	300	III	5692.68	$1w_2$	2	IV A
5587.73	$1w_3$	2	IV A	5694.05	$1w_1$	2	IV A
5589.28	$2w_3$	4	IV A	5696.3	1—	1	IV
5591.60	4	4	IV	5696.50	1—	....	V E
5592.25	$40w_2$	60	III	5696.8	1	1	V
5593.10	$5w_1$	20	IV A	5697.44	1—	....	V E
5593.22	1—	....	V E	5699.84	$1w_1$	1	IV
5598.5	$1w_1$	....	V	5705.82	1—	....	V E
5599.11	$15w_1$	20	IV	5706.22	1	....	V
5599.80	$60w_1$	80	III	5707.57	1—	....	V E
5601.3	$1w_3$	1	IV	5707.89	4	8	IV A
5602.7	1—	....	V	5709.3	$1w_3$	1	IV
5605.86	60	60	III	5714.39	$1w_3$	1	IV
5607.38	8	20	IV A	5717.9	1—	....	V
5609.70	$2w_1$	2	IV	5718.81	$8w_3$	8	IV
5612.2	$1w_3$	1	IV	5721.87	1	1	IV
5617.05	$4w_2$	4	IV	5725.74	1—	....	V E
5618.81	$150w_1$	200	III	5727.31	1	1	IV
5619.50	1	1	IV	5728.20	$12w_1$	20	IV
5620.23	1	1	IV	5730.87	$500w_2$	400	II
5621.87	1	....	V E	5731.56	$6w_3$	8	IV
5622.44	$600w_1$	400	II	5732.72	1	1	IV
5626.04	1	....	V	5734.4	$1w_1$	....	V
5627.07	10	10	IV	5736.61	$12w_1$	15	IV
5629.42	1—	....	V E	5737.2	$1w_2$	....	V
5632.54	600	400	II	5738.22	$1w_2$	2	IV A
5635.16	2	4	IV A	5739.000	400	200	III
5638.41	$2w_4$	2.	IV	5740.9	1	....	V
5640.22	$5w_3$	8	IV	5743.4	1	....	V
5645.795	1200	1000R	I	5743.9	1	....	V
5649.81	1—	....	V E	5744.36	$12w_1$	12	IV
5649.88	8	15	IV A	5749.02	$3w_2$	....	V E
5650.28	8	12	IV	5750.90	1	2	IV A
5651.11	30	30	III	5758.03	1—	1	IV A
5653.33	1	....	V	5760.97	1	1	IV
5654.65	$10w_1$	30	III A	5763.94	1	....	V E
5655.8	1—	....	V	5765.20	2500	2000r	I
5657.57	1	1	IV	5766.80	3	3	IV
5659.87	1	....	V	5767.61	10	....	V E
5665.35	$8w_2$	15	III A	5769.56	$3w_1$	3	IV
5668.23	$6w_2$	8	IV	5769.88	1	2	IV A
5670.1	$1w_3$	1	IV	5774.5	1	....	V
5671.53	1—	2	IV A	5778.4	1	....	V E
5671.80	1	2	IV A	5778.90	1	1	IV
5673.85	600	400	II	5781.3	1	....	V E
5674.98	10	10	IV	5783.69	$1200w_2$	1000	II
5676.60	1—	1	IV A	5787.34	1—	....	V E
5681.099	$100w_1$	150	III	5787.4	$1w_2$	1	IV
5682.25	1—	1	IV A	5789.34	1	....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
5789.41	$1w_2$	2	IV A	5888.72	1	3	IV A
5792.08	1	1	IV	5891.30	10	12	IV
5792.72	50	30	III	5895.31	40	40	III
5794.61	$6w_2$	....	V E	5899.3	$1w_3$	....	V
5796.0	$1w_2$	....	V	5901.28	1—	....	V E
5797.4	$1w_2$	....	V	5902.77	125	80	III
5800.27	800	600	II	5906.26	$4w_3$	....	V
5803.92	1—	....	V E	5908.76	$8w_1$	15	IV A
5805.68	20	20	III	5909.41	10	20	IV A
5807.7	$1w_4$	....	V	5909.94	$60w_2$	125	III A
5809.9	1	1	IV	5914.66	$20w_2$	30	III
5811.0	1	....	V	5915.74	$800w_2$	600	III
5811.37	1—	....	V E	5921.0	1	....	V
5815.46	1—	....	V E	5921.56	1—	....	V E
5817.65	$1w_2$	1	IV	5922.30	1—	....	V E
5818.74	1000	10	IV E	5924.91	15	15	III
5820.03	50	40	III	5925.30	40	25	III
5820.80*	25	8	IV	5926.52	300	250	III
5820.91		....	V E	5927.03	1	1	IV
5822.52	1—	....	V E	5929.1	1—	....	V
5826.5	$1w_2$	1	IV	5931.8	1—	....	V
5827.75	$1w_3$	....	V	5937.77	$15w_1$	15	IV
5829.49	$50w_3$	100	III A	5940.9	1	....	V
5830.98	5000	4000	II	5941.6	1	....	V
5832.68	1	1	IV	5942.72	150	100	III
5835.18	1—	....	V E	5948.5	$1w_2$	....	V
5838.03	15	15	III	5950.37	2	2	IV
5843.55	12	12	IV	5951.22	$2w_3$	2	IV
5844.62	1	....	V E	5953.49	60	60	III
5845.77	50	50	III	5953.84*	80	....	V E
5846.37	$1w_2$	2	IV A	5953.97*		20	IV
5849.7	1	1	IV	5954.28	60	150	III A
5852.42	$3w_4$	6	IV A	5955.75	$8w_2$	20	IV A
5853.70	2	....	V E	5961.1	1—	....	V
5854.13	1	1	IV	5963.76	400	300	II
5855.90	1—	....	V E	5964.85	$1w_3$	1	IV
5856.95	20	20	III	5966.07	1200	15	IV E
5860.97	80	80	III	5967.10	$2500w_2$	2000	II
5864.77	40	40	III	5968.43	40	40	III
5866.67	40	80	III A	5970.87	6	10	IV
5867.82	$3w_2$	6	IV A	5971.69	60	50	III
5872.98	500	6	IV E	5972.75	$800w_1$	600	II
5874.2	$1w_3$	....	V	5973.71	5	8	IV
5874.87	1	1	IV	5975.80	$1w_1$	2	IV A
5876.0	$1w_2$	1	IV	5977.41	$2w_1$	5	IV A
5879.85	1—	....	V E	5979.99	6	20	III A
5880.42	$1w_2$	....	V E	5980.47	30	30	III
		3	IV A	5983.14	$80w_2$	150	III A
5880.81	3	....	V E	5983.78	60	50	III
5884.83	15	15	IV	5986.84	8	15	IV A
5885.15	10	12	IV	5987.5	1—	....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
5990.65	1	1	IV	6105.67	1	2	IV A
5992.83	$1500w_1$	1000	II	6107.51	15	15	IV
5994.31	1	2	IV A	6108.15	150	50	III
6003.02	$50w_3$	100	III A	6110.78	1−	....	V E
6004.36	300	200	II	6111.00	$3w_2$	3	IV
6005.07	1−	1	IV A	6111.88	$2w_2$	4	IV A
6005.61	60	80	III	6118.11	6	12	IV A
6005.8*	$15?w_3$	15?	III	6118.78	$400w_2$	300	II
6012.20	$300w_3$	200	II	6119.35	2	5	IV A
6012.56	400	300	II	6124.67	150	150	II
6015.58	150	60	III	6126.82	3	4	IV
6016.07	8	10	III	6132.19	1−	....	V E
6016.40	$4w_2$	20	III A	6133.26	1	2	IV A
6018.15	2500	2000	I	6139.15	$6w_1$	12	IV A
6021.82	1	....	V	6140.11	$3w_1$	....	V
6023.15	250	200	II	6147.04	1	....	V E
6025.11	2	3	IV	6147.83	1−	....	V E
6027.08	1	2	IV A	6149.00	1	2	IV A
6029.00	600	400	II	6149.28	5	12	IV A
6032.42	10	10	IV	6150.11	4	8	IV A
6033.08	1	1	IV	6152.94	$2w_2$	6	IV A
6040.05	$1w_4$	4	IV A	6153.27	40	80	III A
6040.87	8	8	IV	6154.1	$1w_2$	....	V
6042.88	$1w_4$	2	IV A	6155.36*	$15w_4$	15	IV
6044.66	250	200	II	6158.71	10	10	IV
6045.39	1−	....	V E	6164.14	4	5	IV
6049.51	2000	20	IV E	6170.72	1−	3	IV A
6051.28	6	6	IV	6171.17	2	4	IV A
6052.23	5	20	IV A	6173.05	2000	15	IV E
6052.3	2?	4	IV A	6176.0	1	....	V
6052.81	$8w_2$	....	V E	6178.76	150	60	III
6052.89		25	III A	6179.63	2	6	IV A
6057.36	$600w_1$	400	II	6185.05	1−	....	V E
6061.71	$10w_4$	....	V E	6185.27	5	5	IV
6062.3	1	1	IV	6186.45	$2w_2$	4	IV A
6064.2	1	....	V	6188.13	$1500w_2$	1200	II
6065.3	$1w_3$	....	V	6190.2	$2w_2$	2	IV
6066.2	$1w_3$	....	V	6191.27	5	5	IV
6072.75	$4w_3$	....	V E ?	6193.90	2	4	IV A
6074.30	10	10	IV	6195.07	600	600	II
6075.58	300	250	II	6195.74	1−	2	IV A
6077.38	$100w_2$	100	III	6196.94	2	6	IV A
6078.52	1	....	V E	6197.39	1−	....	V E
6079.99	$15w_3$	2	IV	6199.9	$2w_2$	....	V
		....	V E	6201.65	$2w_2$	3	IV
6080.94	$6w_2$	8	IV	6202.3	1−	....	V E
6081.82	1	....	V E	6205.07	1−	....	V E
6083.84	$1200w_2$	1000	II	6207.60	50	100	III A
6099.35	$1200w_1$	1000	II	6209.35	10	10	III
6100.05	12	15	IV	6210.35	1−	....	V E
6102.81	$2w_2$	2	IV	6213.30	1−	....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
6214.3	$1w_2$	2	IV A	6369.25	400	400	II
6217.3	$1w_2$	2	IV A	6369.6*	?	5?	IV A
6218.80	$1w_2$	6	IV A	6371.90	1	....	V
6224.28	1−	....	V E	6373.34	$10w_2$	30	III A
6230.51	40	80	III A	6378.49	1	....	V E
6231.95	1	2	IV A	6382.73	300	250	II
6233.73	300	300	III	6383.86	500	400	II
6236.90	1−	2	IV A	6389.58	15	40	III A
6240.71	8	8	III	6398.22	1−	....	V E
6242.0	1	1	IV	6400.93	1000	800	II
6245.91	$10w_2$	20	III A	6402.94	1−	....	V E
6249.31	1−	....	V E	6403.2	1	....	V
6249.51	1−	1	IV A	6404.4	$1w_2$	....	V
6250.47	150	200	II	6406.11	200	300	II
6255.65	$1w_2$	2	IV A	6410.04	$1200w_2$	1000	II
6260.16	$4w_2$	10	III A	6411.32	600	300	II
6262.25	1500	1500	II	6413.19	1	2	IV A
6263.42	20	40	III A	6428.29	300	200	II
6264.60	15	30	III A	6429.44	2	10	III A
6266.95	150	300	I A	6435.35	$8w_2$	30	III A
6280.51	1	....	V E	6437.64	4000	40	III E
6283.87	1	2	IV A	6439.93	60	100	II
6284.86	2	4	IV A	6449.79	1	....	V E
6285.95	$80w_2$	150	III A	6457.96	600	500	II
6287.45	1	3	IV A	6465.3	$2w_3$	....	V
6288.95	30	30	III	6467.44	10	30	III A
6291.34	300	600	I A	6469.65	1	2	IV A
6291.79	15	30	III A	6470.70	$80w_1$	150	II A
6294.86	1−	1	IV A	6471.99	$1w_2$	....	V
6295.0	1	....	V E	6476.55	$20w_3$	60	III A
6298.08	2	3	IV	6483.02	100	150	II
6299.77	800	600	II	6501.55	300	300	II
6300.42	20	40	III A	6505.48	1	....	V
6303.41	2000	15	IV E	6507.60	3	8	IV A
6304.00*	?	5	IV A	6519.59	600	600	II
6308.1	$2w_3$	2	IV	6522.72	80	100	III
6309.6	$2w_3$	....	V	6524.09	1	....	V E
6311.87	$2w_3$	....	V E	6530.63	4	....	V
6313.78	$100w_1$	200	III A	6532.96	$6w_2$	20	III A
6317.87	3	10	IV A	6539.02	2	4	IV A
6318.58	30	30	III	6543.8	$3w_3$	....	V
6324.42	40	100	IV A	6549.12	60	100	III
6333.5	1	....	V	6558.12	1	....	V
6335.82	400	400	II	6561.17	$20w_2$	50	III A
6341.71	1	....	V E	6567.87	600	600	II
6350.04	$1000w_2$	800	II	6569.9	1	....	V
6355.89	300	300	II	6570.76	20	20	III
6360.48	3	20	III A	6572.9	3	....	V
6360.83	1	3	IV A	6574.0	1	....	V
6363.78	1−	....	V E	6578.3	2	6	IV A
6366.76	$4w_1$	10	III A	6581.0	1	3	IV A

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
6587.0	$2w_2$	2	IV	6804.47	1	....	V
6592.9	$3w_2$	5	IV	6816.06	800	1500	III A
6593.79	400	400	II	6820.70	$1w_2$	....	V
6595.97	$1w_2$	....	V	6821.59	$2w_2$	....	V
6601.1	$3w_2$	5	IV	6822.61	$20w_2$	30	IV
6603.55	$200w_3$	400	III A	6830.7	$1w_4$	1?	IV ?
6603.7*	10?	10?	III	6834.30	$100w_2$	100	III
6619.19	$6w_1$	25	III A	6839.0	1	....	V
6621.22	3	8	IV A	6840.93	$200w_2$	200	III
6623.3	1	2	IV A	6844.83	$200w_3$	400	III A
6623.72	3	4	V E, IV	6847.04	$100w_2$	150	III
6639.52	1—	....	V E	6851.38	2	....	V E
6640.8	3	3	IV	6861.33	3	....	V E
6645.11	8000	80	III E	6864.54	3000	3000r	I
6663.3	1	1	IV	6890.75	3	6	IV A
6666.48	1—	....	V E	6898.21	$150w_1$	150	III
6668.97	1	....	V	6901.13	$1w_2$	....	V
6671.89	$10w_2$	10	IV	6903.67	$1000w_1$	600	III
6681.6	1	5	IV A	6906.27	1	....	V
6682.00	$15w_3$	15	IV	6908.71	10	20	IV A
6683.3	$1w_2$	1	IV	6910.17	$50w_2$	60	III
6685.21	400	300	II	6914.82	$150w_1$	150	III
6691.0	1	....	V	6918.36	$1w_2$	....	V
6692.98	1	....	V	6947.49	2	2	IV
6693.96	1500	1200	II	6950.72	$8w_2$	....	V E
6695.84	$4w_2$	8	IV A	6951.66	6	....	V E
6701.06	$20w_1$	40	III A	6957.42	10	....	V E
6707.00	$2w_2$	....	V	6962.31	2	....	V E
6710.45	$30w_2$	30	III	6965.76	$10w_3$	....	V E
6727.80	2	....	V	6973.34	$8w_2$	15	IV A
6732.36	$4w_2$	6	IV	6978.18	$15w_1$	....	V E
6733.8	$2w_3$	....	V	6982.60	3	2	IV
6735.0	$3w_2$	5	IV	6983.61	6	....	V E
6741.9	2	4	IV A	6984.3*	2	....	V
6744.88	600	600	II	6985.6*	$3w_2$	....	V
6750.30	1	....	V	7015.12	20	....	V E
6752.6	2	2	IV	7030.71	4	....	V E
6755.0	$1w_3$	....	V	7032.16	2	....	V
6755.82	2	2	IV	7036.23	$3w_2$	3	IV
6757.32	10	....	V E	7040.20	2500	2000	II
6758.53	$8w_3$	8	IV	7047.54	6	....	V E
6765.47	2	....	V E ?	7050.14	5	....	V E
6766.60	$2w_3$	....	V	7058.34	$6w_3$	....	V E
6772.44	$8w_2$	10	IV	7058.83	4	....	V E
6782.54	600	1200	III A	7063.6	1	....	V
6782.7*	20?	40?	III A	7066.0	1	....	V
6784.87	$4w_4$	5	IV	7068.93	1	....	V
6787.48	$300w_2$	600	III A	7073.65	$2w_2$	....	V E
6791.6	$2w_4$	....	V	7074.54	150	300	II A
6799.19	1	....	V	7077.10	3000	30	IV E
6802.72	2500	2500	II	7080.30	2	....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
7092.71	$2w_2$	....	V E	7404.70	$15w_3$	15	IV
7106.48	1500	1500	I	7409.53	6	....	V E
7114.48	6	....	V E, V	7426.57	1500	15	IV E
7114.9*	8?	....	V	7436.59	$200w_1$	150	III
7129.33	4	5	IV	7444.62	$15w_2$	12	IV
7139.6	$4w_2$	....	V E	7450.34	5	15	III A
7148.80	8	....	V E	7455.52	2	....	V E
7162.49	$5w_2$	....	V E	7470.53	$50w_2$	100	II A
7164.66	$40w_1$	40	III	7481.52	$2w_2$	2	IV
7169.87	2	....	V E	7491.00	$30w_2$	30	IV
7175.0	$15w_3$	10	IV	7492.24	2	....	V E
7175.55	$200w_2$	200	II	7507.02	8	10	IV
7179.05	2	....	V E	7508.50	20	40	III A
7180.2	3	2?	IV ?	7521.25	$8w_1$	8	IV
7194.81	1500	15	IV E	7528.70*	$400w_3$	400	II
7201.70	2	....	V E	7531.81	2	....	V E
7204.41	15?	30	III A	7532.17	4	5	IV
7217.55	1500	15	IV E	7533.02	30	60	II A
7224.68	100	150	III	7534.81	2	....	V
7234.03	2	....	V E	7536.71	2	....	V E
7248.08	$20w_2$	30	IV	7547.32	$40w_1$	80	II A
7258.72	$80w_2$	100	III	7552.00	8	30	III A
7262.77	$200w_1$	300	II	7578.41	1	....	V
7270.06	$3w_2$	....	V E	7583.91	1000	500	II
7281.53	$40w_2$	40	III	7603.05	1	1	IV
7297.56	$20w_1$	30	IV	7603.87	6	20	IV A
7301.17	2500	25	IV E	7627.65	8	25	IV A
7310.46	$40w_2$	40	III	7633.5	2	....	V
7313.63	$100w_1$	200	II A	7650.7	2	....	V
7323.00	2	....	V E	7678.15	1	....	V
7330.93	4	....	V E	7683.6	2	....	V
7336.18	$800w_4$	800	II	7704.9	$2w_2$	....	V
7340.09	8	....	V E	7707.21	$1w_2$	....	V
7346.25	20	20	III	7708.52	1	....	V
7350.47	$6w_2$	....	V E	7710.92	$4w_2$	8	IV A
7356.65	25	25	III	7725.95	4	....	V
7362.25	$80w_2$	100	II	7742.57	$300w_3$	250	II
7365.70	6	....	V E	7746.19	500	200	II
7367.70	$10w_2$	10	IV	7759.36	4	5	IV
7369.60	$600w_4$	600	II	7787.6	$2w_3$	....	V
7370.22	2500	25	IV E	7803.32	$50w_4$	100	III A
7374.32*	$4w_3$	....	V	7818.21	40	30	III
7376.98	3	....	V	7830.60	$3w_1$	1?	IV ?
7378.15	4	....	V E	7848.69	$8w_2$	15	IV A
7387.36	20	40	III A	7850.07	$3w_2$	3	IV
7389.16	$150w_2$	150	II	7874.68	$3w_3$	1?	IV ?
7392.70	5	5	IV	7882.34	30	30	III
7394.86	$12w_2$	12	IV	7887.99	500	300	II
7399.96	$4w_3$	8	IV A	7890.52	$5w_1$	2?	IV ?
7402.06	$4w_2$	10	IV A	7901.86	5	3?	IV ?
7404.41	$40w_2$	40	III	7908.69	3	—?	V ?

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
7963.77	1	....	V	8782.46	10	2	IV
7969.02	$4w_3$	4	IV	8785.06	$4w_2$	....	V
7987.0	2	....	V	8789.33	$3w_2$	....	V
7998.43	$3w_3$	2	IV	8790.88	25	1?	IV ?
8015.47	50	40	III	8791.1	$6w_2$	....	V
8050.53	$6w_2$	4	IV	8812.9	$1w_3$	....	V
8080.5	3	1?	IV ?	8816.95	$4w_2$	....	V
8133.75	5	4	IV	8821.57	$1w_2$	....	V
8168.09	30	30	III	8836.27	1	....	V
8209.80	$500w_3$	400	II	8860.0	1	....	V
8226.81	$250w_3$	200	II	8870.30	40	2	IV
8253.82	15	20	III	8880.81	$2w_2$	....	V
8274.62	10	12	IV	8883.03	$2w_2$	....	V
8335.56	$10w_2$	12	IV	8885.5	$1w_3$	....	V
8372.0	$20w_5$	15	IV	8893.26	2	....	V
8376.23	$3w_2$	....	V	8899.94	8	....	V
8441.5	1	....	V	8917.64	$20w_2$	....	V
8464.71	$40w_3$	80	III A	8934.42	12	....	V
8476.74	2	....	V	8935.59	$5w_3$	....	V
8507.34	$2w_3$	....	V	8961.69	$3w_3$	....	V
8514.65	8	15	IV A	8964.3	$4w_3$	....	V
8540.4	$1w_3$	....	V	8965.46	4	....	V
8597.19	$15w_2$	15	IV	8975.70	$2w_3$	....	V
8631.74	$4w_3$	....	V	8982.50	4	....	V
8632.8	1	....	V	9018.06	5	....	V
8641.69	$6w_2$	5	IV	9024.33	3	....	V
8642.67	$200w_2$	150	III ?	9058.00	2	....	V
8654.10	2	....	V	9072.4	$1w_3$	....	V
8658.55	$2w_3$	....	V	9083.06	$10w_1$	....	V
8665.21	4	4	IV	9085.33	3	....	V
8668.1	$1w_2$	....	V	9220.95	$8w_4$	....	V
8688.71	2	....	V	9326.08	$4w_3$	....	V
8704.50	$6w_2$	2	IV	9455.92	$5w_2$	....	V
8709.31	$1w_2$	....	V	9883.16*	10	....	V E
8710.39	$2w_2$	....	V	9898.30*	40	....	V E
8727.77	$30w_3$	5	IV	9998.65*	15	....	V E
8738.6	$4w_4$	....	V	10017.3*	1	....	V E
8740.7	$2w_2$	....	V	10019.58*	30	....	V E
8743.83	$10w_2$	....	V	10034.22*	12	....	V E
8745.6	$2w_3$	....	V	10066.03*	8	....	V E
8749.62	4	....	V	10142.99*	2	....	V E
8751.66	$6w_4$	1?	IV ?	10165.61*	5	....	V E
8773.30	$3w_3$	....	V				

NOTES TO TABLE 2

λ	
2207.97	Intensity varied on different plates. May be impurity
2237.67	Probably double
2347.05	Red side stronger
2465.89	Unresolved doublet
2626.776	Very faint in spark
2658.41	Very faint in spark
2766.3	Much enhanced unless spark line is *Eu* III
2795.53	Possibly *Mg* II at .54. Companion *Mg* II at λ 2802.7 would be masked by strong *Eu* II
2810.71	Spark line appears slightly to red of arc line
2817.6	Spark line narrow. May be blend with wide *Eu* I
2828.81	Blend in arc with λ 2828.72
2840.14	Narrow in spark
2876.06	Very faint in spark
2893.83	Close coincidence *Eu* I, II
2906.4	Blend with λ 2906.68
2952.68	Complex, shaded to red
2960.21	Complex, shaded to red
2976.58	Spark line may be *Eu* III
2978.950	Much enhanced, or blend *Eu* III in spark
3039.884	May be *Eu* II. Blend *Eu* III in spark
3055.04	Blend with λ 3054.94
3128.90	Faint in spark
3182.86	Blend with λ 3182.98
3213.75	Coincides with faint *Eu* II
3246.47	Blend λ 3246.39
3247.550	Not *Cu* .548, as *Cu* λ 3274 absent
3266.39 3272.77 3277.78 3301.95 3308.02 3313.33 3319.89 3338.75	These lines are distinctive with a sharp maximum, which was measured as closely as possible, and a strong shading to the red. Moderate strength in the spark
3405.40	Measured in furnace. Blend λ 3505.43 in arc
3429.25 3429.33	Not fully resolved
3457.050	Furnace λ. Close blend with *Eu* II, in arc
3470.25	Furnace λ. Arc line blurred, with core at .29
3472.10	λ for sharp furnace line. Arc line wide
3472.71 3472.75	Not fully resolved
3473.60	λ for sharp furnace line. Arc line wide
3476.98 3477.07 3477.19	Not fully resolved
3506.645	Furnace λ. Blend λ 3506.598 in arc
3532.23	Unresolved doublet
3549.6	Blend λ 3549.71
3576.16 3576.89 3577.11	Very diffuse in arc. Sharp in absorption furnace
3603.20	Double. Violet component stronger
3606.54	Furnace λ. Blend *Eu* II in arc
3611.63	Blend λ 3611.57
3622.48	Furnace λ. Blend in arc with λ 3622.54
3629.80	Superposed on wide line λ 3629.8
3660.01	Furnace λ. Arc line measured λ 3659.92
3678.49	Furnace λ. Blend in arc with ghost
3682.61	Furnace λ. Diffuse arc line measured λ 3682.65
3683.62	Furnace λ. Diffuse arc line measured λ 3683.56
3716.98	Furnace λ. Blend in arc with λ 3716.937
3791.60	Uncertain on account of blend with λ 3791.50
3907.10	λ is for main line blended with unresolved satellite to violet
3917.29	Violet side of blend is strong *Eu* II
3928.87	Close doublet
3930.42 3930.50	Usually blended, with center at .48
3943.97	*Eu* I line measured 44.05, usually masked by *Al*
3971.10	Blends in arc with faint *Eu* I at 71.2
3971.89 3971.98	Usually blended, with center at .96
4006.20	Furnace λ. Arc line is wide blend with center at λ 4006.5
4017.58	Close doublet
4129.64 4129.73	Usually blended, with center at .70
4166.34	Blend faint *Eu* I line, furnace λ.47
4202.69	λ for narrow furnace line. Arc line wide
4204.48	Furnace λ. Blend in arc with λ 4204.91
4228.04	*Eu* II line wide, slightly to red of *Eu* I
4253.93	Furnace λ. Blend in arc with λ 4253.80
4317.40	λ for narrow furnace line. Hazy patch in arc
4354.47	Furnace λ. Blend λ 4354.80 in arc
4383.17	Furnace line may be impurity, as it appeared on one plate only
4405.15	Furnace λ. Blend λ 4405.27 in arc
4435.46 4435.58	λ when blended at .56
4512.24	Furnace λ. Arc line at .14 with slight shading to red
4522.46 4522.59	λ when blended at .57
4522.91	Furnace λ. Usually blended in arc with λ 4522.5
4570.52	Furnace line may be impurity
4626.1	Blend with λ 4627.22
4642.50	Furnace λ. Arc line at .66

λ	
4645.73	Furnace λ. Arc line at .90
4647.41	Furnace λ. Arc line at .48
4653.30	Furnace λ. Arc line at .47
4653.86	Furnace λ. Arc line at 54.0
4667.41	Blend air line in spark
4713.04	Blend faint *Eu* II to violet
5113.0	Blend with λ 5112.85
5168.17	Furnace λ. Blend λ 5168.22 in arc
5183.2	Blend air line in spark. Assigned by Russell to *Eu* II
5189.88	Furnace λ. Arc line at .93
5268.64	Furnace λ. Blend in arc with faint line to red
5271.47	Furnace λ. Blend in arc with λ 5271.96
5357.8	Close blend with λ 5357.61
5407.42	Wide, shaded to red. λ uncertain
5426.8	Blend with λ 5426.943
5481.78	Furnace λ. Center of wide arc line measured .85
5519.73	Measured in spark. Blend in arc with λ 5519.62

λ	
5820.80	Furnace λ. Blend in arc with λ 5820.91
5953.84 5953.97	Measured in spark and furnace, respectively. Blended in arc
6005.8	Blend with λ 6005.61
6155.36	Furnace λ. Blend in arc with faint *Eu* II to red
6304.00	Furnace λ. Blend in arc with λ 6303.41
6369.6	Blend with λ 6369.25
6603.7	Blend with λ 6603.55
6782.7	Blend with λ 6782.54
6984.3 6985.6	May be *CN*
7114.9	Partly *CN*
7374.32	Partly *CN*
7528.70	Apparently blend of sharp line superposed on wide line, to violet of center
9883.16 −10165.61	Measured from second-order *Fe* lines. No basis of comparison of intensities with those of shorter wave lengths

Carnegie Institution of Washington
Mount Wilson Observatory
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PROPER MOTIONS IN THE GALACTIC CLUSTER NGC 752

E. G. EBBIGHAUSEN

ABSTRACT

Proper motions are derived on Allegheny plates for an area of about 50′ diameter centered on the cluster NGC 752. The results are contained in Tables 3 and 4; plots of the motions are found in Figures 1*A* and 1*B*. The positions of the probable cluster members are found in Figures 2*A* and 2*B*. The spectral diagram of the probable cluster members, Figure 3*B*, has reduced the cluster to a narrow sequence. The luminosity function is found in Figure 4.

This paper gives the results of the determination of proper motions in the cluster NGC 752 ($\alpha = 1^h51^m.8$, $\delta = +37°11'$, 1900). Other clusters will be discussed in subsequent papers. NGC 752 was considered an important object for proper-motion studies because of the exceptional character of its spectral diagram. Since no suitable first-epoch plates of NGC 752 were available at the Yerkes Observatory, the writer gratefully appreciates the co-operation of the Allegheny Observatory in supplying the plate material. The first-epoch plates were taken during the years 1915–1918 by Dr. R. J. Trumpler, who called the writer's attention to the existence of these plates. The second-epoch plates were kindly taken by Dr. Keivin Burns.

I. THE MATERIAL

The material available for measurement consisted of five pairs of plates whose average interval was 20.9 years. Three of these pairs had only one image of each star, while one pair had three images and another five images of each star. Table 1 is a list of these plates.

II. MEASUREMENT AND REDUCTION

The procedure adopted in this paper was to obtain for each old plate a new plate taken with the same center but exposed through the glass in order that the two plates could be placed film to film and the measurement done differentially. In the measuring machine each pair of plates was firmly held in contact by means of six clamps, which also held the pair in contact with two sheets of clear glass in

order to form a firm foundation. As is usually done, the x- and y-co-ordinates were made to correspond, respectively, with right ascension and declination.

The measuring device was a micrometer eyepiece fitted with a fixed and a movable wire. The power used was 27. The whole assembly could be rotated in order that the measurements could be made in four position angles, 90° apart. Each pair of plates was first placed in the machine with the north edge upward. For each pair of images the differences, Δx and Δy, were measured in both the direct and reverse directions. After this had been done for all the stars on the pair of plates, the pair was turned 90°, with the north edge to the right; and the same procedure of measurement was again followed. This procedure resulted in the measurement of four values of each of the differences, Δx and Δy, which were averaged to form a mean value of each difference, $\overline{\Delta x}$ and $\overline{\Delta y}$, for each star. The reductions were carried out with the aid of the linear formula

TABLE 1

Old Plate	New Plate	Interval in Years	No. of Images	Limiting Magnitudes	Symbol
3695	56014	22.1	1	14.0	P I
7407	55992	21.1	1	12.2	P V
7408	55993	21.1	1	12.1	P VI
7578	55877	21.0	5	12.4	P VII
14321	55944	19.1	3	12.5, 12.3, 11.9	P II, P III, P IV

$$\overline{\Delta x} = ax + by + c$$

for the x-co-ordinate and a similar one for the y-co-ordinate. No fewer than fifty stars were ever used in the least-squares solution for the reduction constants. In order to select stars of small motion for the comparison stars, one pair of plates was first reduced, using all the stars as comparison stars and then discarding those stars of large motion. For that pair the reduction was again performed with the reduced number of stars, and for each succeeding pair of plates as many of the same comparison stars were used as possible.

Then for each star the computed values of differences, Δx_c and

Δy_c, were obtained; and the proper motion in both co-ordinates was derived by forming the differences

$$\overline{\Delta x} - \Delta x_c = \mu_x \, ,$$

$$\overline{\Delta y} - \Delta y_c = \mu_y \, .$$

With the aid of the scale value (1 mm = 14″.6) and the interval in years the values of μ_x and μ_y were converted into units of ten-thousandths of a second of arc per year.

All of the material was divided into seven groups and designated as P I, P II, ... , P VII. P I, P V, and P VI refer to pairs of plates with one exposure on each. P II, P III, and P IV refer to three sets of images of different exposure times on the same pair of plates. P VII refers to the pair of plates with five exposures each. Instead of treating each set of images as a separate plate, the twenty measured values of Δx and of Δy on P VII were averaged to form a mean value of each difference, and the reductions were carried out, treating the five sets of images as one plate.

When, as in the case of NGC 752, the proper motion of the cluster relative to the noncluster stars is small, the problem of separating the cluster and the noncluster stars requires a high accuracy. The following sources of error are of importance: (1) errors of measurement, (2) differential refraction between the two plates if the plates are taken at different hour angles, (3) shifting of the emulsion, (4) error in the micrometer screw, (5) errors due to changes of temperature during the measurement of the plates, and (6) the magnitude equation. The first source can be reduced in size by measuring several pairs of plates and by measuring the images in both the direct and the reversed directions. The second can be largely eliminated by using the same kind of emulsion for both the old and the new plates and by taking the new plate at the same hour angle as the old plate. The shifting of the emulsion can be minimized by exercising care in the development and the drying of the plates. Errors due to (4) and (5) may be largely eliminated by placing the two plates film to film and making differential measurements. In this fashion the length of the micrometer screw used is always less than 1 mm.

The magnitude equation may be classed as a systematic error, since it superimposes on the proper motion of a star a spurious motion which is a function of the magnitude. This magnitude equation can be evaluated if a number of cluster stars of different magnitude are known. In order to select these stars in a provisional way, the motions derived from P VII were plotted. Near the origin of this plot was found an isolated, elongated group of stars which could be expected to contain a large percentage of cluster stars. Of this group, thirty stars were selected as probably belonging to the cluster. The magnitudes of these stars were then plotted against the values of μ_x and μ_y, respectively, and a straight line was drawn through the mean position of the points on each plot. The value of the magnitude equation for both the x- and y-co-ordinates was then applied to all of the stars on P VII, and a plot of these motions was again made. In this diagram the isolated group was much smaller and was almost circularly symmetrical. From this group the thirty stars lying closest to the center of gravity were used to remove the magnitude equation from all the remaining plates, P I to P VI. The average magnitude equation found from the seven different sets amounted to about $0\overset{''}{.}005$/yr/mag. In order to find whether any magnitude equation remained in the various plates, the differences P I − P VII, P II − P VII, ... , P VI − P VII, were formed for all stars in common to each individual set. When these differences were plotted against magnitude, no residual magnitude equation with respect to P VII was found, except in two cases, where it was small but large enough to be applied. These differences also indicated any systematic differences with respect to P VII, owing to the use of slightly different sets of comparison stars; and, if present, they were applied.

The motions from the various plates were now in a form which would permit them to be combined after the weights of the individual plates P I to P VII had been determined. In order to determine these weights, the differences P I − P VII, ... , P VI − P VII, were again formed. Each group of differences was divided into three subgroups, depending on whether the star belonged to the brightest, the intermediate, or the faintest stars on the plate. For each subgroup the quantity $\Sigma v^2/n - 1 = (\text{m.e.})^2$ was formed.

For each group P I – P VII, ... , P VI – P VII, it was found that the value of the mean error as determined for each co-ordinate and for each magnitude subgroup did not vary sufficiently from the mean of the six values to be considered significant. Hence, the mean value of the mean error was adopted, and no distinction was made as to the co-ordinate or the magnitude group. The actual determination of the weights requires one more set of differences, and these were taken between the two most accurate pairs, namely, P V and P VI. The resulting values of $(\text{m.e.})^2$ were then reduced to relative weights, which are given in Table 2.

TABLE 2

Plate	Wt.	Plate	Wt.
P I	1.0	P V	2.0
P II	0.5	P VI	2.0
P III	1.0	P VII	5.5
P IV	1.5		

With the aid of these weights the motions derived from the various plates were combined and are given in Table 3. The columns give, respectively:

1. The number according to Heinemann's *Catalogue*.[1]

2. The photographic magnitude in Trumpler's system.[2] For the stars having a spectral type given in the third column, magnitudes were kindly supplied by Dr. R. J. Trumpler. For the other stars Heinemann's magnitudes were used, reduced to Trumpler's system by the writer.

3. The spectral type, kindly communicated by Dr. R. J. Trumpler.

4 and 5. The proper motions in x and y expressed in units of $0\rlap{.}''0001$/year.

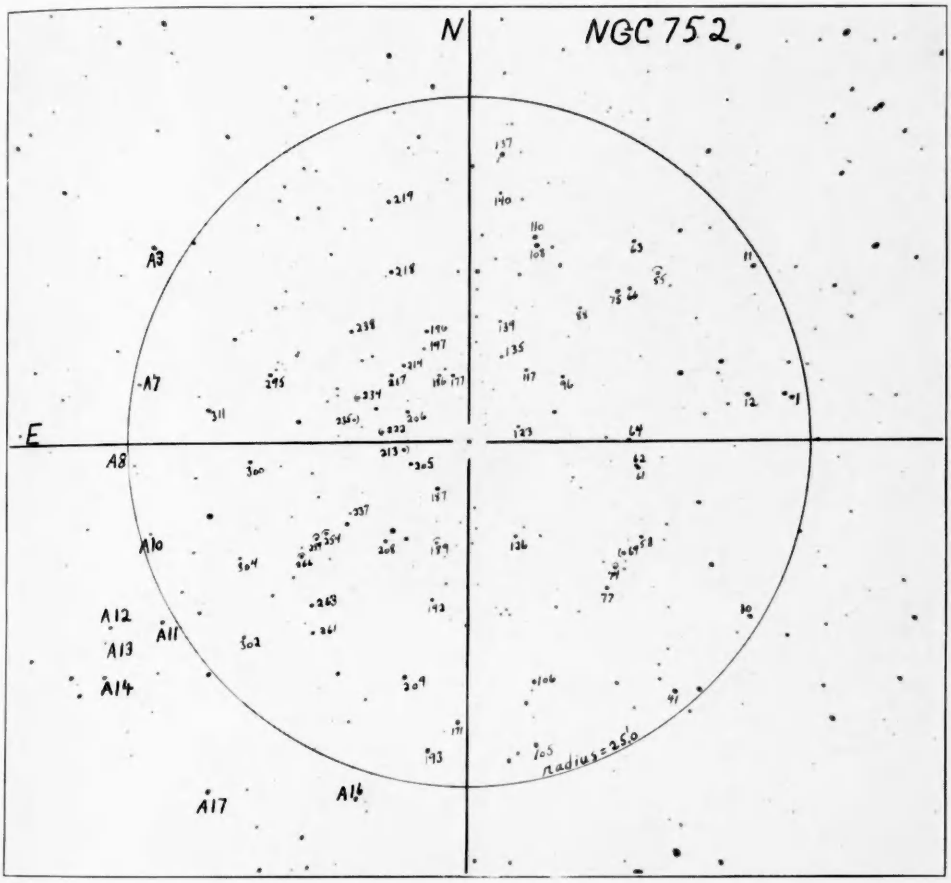
6. The weights of the motions in the preceding columns. Unit weight corresponds to a mean error of $\pm 0\rlap{.}''0033$, as obtained from the internal agreement between the plates. A dot used as a superscript indicates that the given weight p is really $p + \frac{1}{2}$.

[1] *A.N.*, **227**, 213, 1926. [2] Private communication.

TABLE 3

Star	m_{pg}	Spec.	$\mu_\alpha \cos\delta$	μ_δ	Wt.	Membership
1	10.3	....	−30	−23	2	2
3	10.4	....	−39	−8	2	3
10	10.5	....	−15	+3	4	2
11	10.0	....	−24	+17	4	2
12	10.2	....	−21	−37	9*	2
21	12.2	....	−216	+53	7	4
24	9.9	....	−44	−24	12*	3
27	10.0	....	−66	−11	12*	4
32	10.1	....	−113	−39	7*	4
34	10.1	....	−41	−9	13*	3
39	8.9	gG9	−187	+2	11*	4
40	11.4	....	−50	+118	5	4
41	10.1	....	−25	+6	8	2
51	12.5	....	−150	+130	7	4
55	11.6	....	−30	+15	10	2
58	10.6	F3	0	−25	12*	1
61	10.2	F5	−6	−4	13	1
62	11.6	F3	−9	−13	13*	1
63	11.4	....	−10	−30	4	2
64	10.6	....	+3	+9	13*	1
66	11.0	F3	−2	−9	13*	1
68	12.3	....	−104	+81	3*	4
69	10.4	F3	+22	−6	13*	1
73	11.4	....	−86	+76	12*	4
74	11.0	F2	−6	+1	13*	1
75	9.8	gK2	−24	+7	13*	2
77	10.9	gG8	−30	+1	13*	2
78	12.1	G0	−467	−320	8	4
88	12.2	F3	+23	−15	10	1
91	12.3	K	+45	+141	1*	4
96	10.3	F2	+10	−6	13*	1
99	12.1	A0	−65	+160	8	4
101	11.9	....	+496	−25	12	4
102b	10.0	F3	−235	−54	13*	4
102ft	11.6	....	−237	−59	11*	4
103	12.1	K0	−94	+162	6	4
105	10.4	....	−10	+32	13*	2
106	10.6	....	−18	+1	13*	1
108	9.4	F2	−32	−7	8	2
110	9.7	gG2	−11	−11	5	2
114	10.9	....	−85	+48	13*	4
117	10.5	F3	+11	−2	11*	1
120	12.6	....	+53	−19	6	3
123	11.4	F0	+16	−2	10*	1
124n	11.9	....	−13	+130	1*	4

PLATE XXIII



FINDER CHART FOR NGC 752

The circle has a radius of 25′ with star No. 166 as center. The numbers which are not preceded by *A* refer to stars whose membership class is either 1 or 2. Those numbers which are preceded by *A* refer to stars which were measured but had no Heinemann number.

TABLE 3—*Continued*

Star	m_{pg}	Spec.	$\mu_\alpha \cos \delta$	μ_δ	Wt.	Membership
124s	11.9	....	+32	+120	1*	4
126	10.3	F4	+10	−4	13	1
129	11.0	....	+17	+42	12*	3
132	12.8	....	−113	+41	1*	4
135	11.5	F2	+8	+2	13*	1
137	9.9	....	−3	−35	2	2
139	12.1	F3	+16	+12	10	1
140	12.0	....	+3	−43	3	2
159	9.7	F5	−41	+7	10*	3
161	12.5	....	+54	+25	7*	3
163	12.7	....	+74	+50	2	3
165	11.3	....	−152	+62	2	4
166	10.1	F2	−28	+25	13*	3
171	10.4	....	0	+24	11*	2
177	10.5	F6	+42	−12	12	2
185	12.6	....	+53	−67	1*	3
186	11.0	gK0	−2	+6	8	2
187	10.7	F2	+13	−5	13*	1
189	11.5	F2	−10	0	13*	1
192	10.8	F3	+2	−22	12*	1
193	10.2	....	−17	+2	12*	1
196	10.5	F5	+13	−2	13*	1
197	11.9	F3	+17	+11	13*	1
205	10.2	F2	+3	−18	13*	1
206	10.4	F5	+5	−12	13*	1
208	9.9	gG9	−18	−12	12	1
209	9.5	....	−27	−6	13*	2
213	10.0	....	−16	−13	13*	1
214	10.7	F2	+32	−15	13*	2
215	8.2	gK3	−21	−181	6*	4
217	10.7	F3	+3	−7	13*	1
218	10.3	....	+6	−20	13*	1
219	10.7	....	+28	−26	5	2
220	10.5	gK0	+287	−330	11*	4
222	11.3	F3	+6	−6	13*	1
225	10.6	F8	−114	+139	13*	4
226	12.7	G0	+110	−35	7	4
232	12.0	F4	+52	−17	12	3
234	11.0	F2	+36	−4	13*	2
235	11.7	F6	+4	−4	13*	1
237	12.6	....	+24	−12	1*	2
238	10.2	F2	+11	−12	13*	1
240	10.1	F6	−303	−177	13*	4
246	10.6	....	+147	−671	13*	4
250	12.0	F1	+55	+23	12	4

TABLE 3—*Continued*

Star	m_{pg}	Spec.	$\mu_\alpha \cos \delta$	μ_δ	Wt.	Membership
253	12.4	....	− 67	−580	1*	4
254	11.1	F3	− 3	− 21	11*	1
255	12.8	F9	+200	−142	1*	4
258	12.5	F9	+ 11	− 55	7	3
259	11.6	F4	+ 23	− 15	13*	1
260	12.3	....	−169	+110	3	4
261	11.4	....	+ 10	− 23	13*	1
263	11.0	....	0	− 12	13*	1
264	12.4	F5	+ 8	+ 48	7	3
266	11.5	F5	+ 13	− 27	13*	1
271	9.3	F2	−143	−133	13*	4
272	12.9	....	− 22	+126	1*	4
273	11.7	F5	+ 9	+ 59	13*	4
275	12.5	....	+ 50	− 80	1*	3
293	12.2	....	+ 39	− 38	10	3
295	10.0	gK0	− 1	− 18	13*	1
300	9.8	F2	− 1	− 16	13*	1
302	11.6	....	+ 9	− 28	13*	1
304	12.2	....	+ 31	− 12	10	2
306	10.7	....	−103	+ 68	13*	4
308	11.1	....	−239	+ 85	13*	4
309	8.2	....	−242	− 28	3	4
311	9.9	....	− 7	− 18	13*	1
314	11.9	....	+116	− 54	10	4
316	12.3	....	− 2	+108	1*	4
319	12.4	....	− 24	+128	1*	4
A3	9.2	....	− 55	− 28	3	3
A7	12.3	....	+228	−422	10	4
A8	12.6	....	+ 34	− 66	1*	3
A10	12.4	....	+210	−326	1*	4
A11	11.6	....	− 65	+ 91	13*	4
A12	12.3	....	− 80	+128	1*	4
A14	11.6	....	− 82	+ 4	3	3
A16	10.6	....	+ 4	− 31	8*	2
A17	10.2	....	+ 37	− 50	8*	3

7. A measure of the probability that the star is a member of the cluster. The figure 1 indicates that the star has a high probability of being a cluster member; 2 indicates that the probability is lower but that the star has a reasonable chance of being a member; 3 denotes that the star is probably not a member; and 4 signifies that the star is definitely not a cluster member. The assignment of membership will be discussed in Section III.

The plates had roughly the same limiting magnitude, except P I, which went down to 14.0. Since the faint stars on this pair of plates could not be measured on any other pair, their motions have a rather small accuracy. The magnitude equation for these stars was obtained by simply extrapolating the straight line indicated by the brighter stars on the same plate. These stars are given in Table 4, where column 1 gives Heinemann's number, column 2 gives Heinemann's photographic magnitude, and columns 3 and 4 list the proper motions in x and y in units of $0\overset{''}{.}0001$/year.

III. DISCUSSION OF THE RESULTS

The data given in Table 3 are complete down to about $m_{pg} = 12.2$, within a radius of 25′ of star No. 166, which is the origin of the co-ordinates given by Heinemann. This does not, however, apply to a small portion of the northernmost part of the cluster, which was not covered by the plates. The spectra given by Trumpler are complete down to $m_{pg} = 10.7$, but only three stars brighter than 12.5 have not been classified. These stars with spectra all lie within a radius of $16\overset{'}{.}7$ (1000″) of star No. 166.

The weights assigned to the individual stars range from 1.5 to 13.5. A weight of 13.5 corresponds to a mean error of $\pm 0\overset{''}{.}0009$/year in either co-ordinate. Figure 1*A* is a plot of all stars having a weight $p > 10$. Figure 1*B* is a plot of all stars with $p \leq 10$. The stars with a weight of $9\frac{1}{2}$ and 10 are indicated by circles crossed with a horizontal line. Stars with $5 \leq p \leq 8\frac{1}{2}$ are circles, and those with $p < 4$ are plain dots.

The assignment of probability of membership in the cluster was made in the following manner. The average weight of the stars in Figure 1*A* corresponds to a mean error of $\pm 0\overset{''}{.}0010$/year. Three circles were drawn with their centers at the center of gravity of the concentration. The radii of these circles are 2.5, 4.0, and 6.0 times the mean error just given. Stars falling within the inner circle were assigned to class 1; stars between the first and second circles were assigned to class 2; those between the second and third circles, to class 3; and those outside the third circle, to class 4.

The stars in Figure 1*B* were divided into three groups: (1) $p = 9\frac{1}{2}$ and 10, (2) $5 \leq p \leq 8\frac{1}{2}$, and (3) $p < 4$. No stars had a weight of $4\frac{1}{2}$ or 9. The mean errors corresponding to the average weight of the

TABLE 4

No.	m_{pg}	$\mu_\alpha \cos\delta$	μ_δ
8	13.7	−16	+20
16	12.8	−39	+20
20	13.3	+23	+130
26	12.4	−13	+18
28	12.9	+80	+128
30	12.4	−120	+76
36	13.4	−142	+49
37	12.4	+2	+10
44	13.3	+124	−101
45	13.1	+26	+189
48	12.6	+34	−44
49	13.2	−67	+110
50	13.4	−33	+76
52	12.9	+237	+146
56	13.7	+55	−52
59	13.3	−52	+179
65	13.9	−67	+5
67	13.8	−2	+78
71	14.0	+28	+117
76	13.8	−59	+63
80	13.2	+50	−34
86	12.9	−72	+54
87	13.0	+98	−18
92	13.9	+37	+150
95	13.6	+57	+125
98	14.0	−63	+133
100	13.5	+16	+76
104	13.1	−6	+106
107	13.6	+106	−13
109	13.3	−81	+99
112	13.9	−60	+159
118	12.7	−39	+120
121	12.7	+21	+179
128	13.6	+44	+109
130	13.2	−111	+86
141	13.8	−57	+132
144	13.4	−50	+81
145	13.0	−20	+89
146	13.5	+83	0
148	14.1	−75	+68
149	14.2	0	+203
151	12.6	+73	+5
154	13.6	−20	+57
157	12.8	+29	+8
160	12.8	+2	+85
162	13.3	−6	+94
164	12.8	−15	+67
167	13.4	+80	+8
168	13.2	−109	+148
170	13.3	−6	+174
175	13.5	+296	+101
176	12.3	+81	−63
182	12.6	+63	−52
184	12.8	+52	+52
190	14.0	−46	+107
207	13.7	+93	−2
221	13.6	−3	+133
228	12.7	−233	+159
229	12.9	+42	+49
230	13.9	+23	+98
231	13.2	−39	+122
236	12.8	+24	+41
244	13.1	+42	+42
248	13.1	+76	+67
249	13.2	−6	+78
251	14.0	+57	−96
252	13.2	+31	+44
256	13.7	+37	+83
265	13.6	+60	0
267	13.5	−107	+88
269	14.0	+2	+143
274	11.8	−20	+80
276	14.3	+93	+197
277	13.0	−23	+18
280	14.0	−291	+125
281	13.0	−132	+62
282	13.4	−59	+99
283	14.2	−13	+107
284	12.5	−57	+99
285	13.7	+13	+44
286	13.7	+390	+966
287	13.1	−89	+156
289	12.4	−50	+28
290	13.3	−85	+174
291	12.8	+37	+76
292	12.5	−37	+24
297	14.1	+265	+54
299	12.7	−34	+72
301	13.8	−37	+58
313	13.5	+86	+5
315	12.8	−76	+166
318	13.0	−47	+135
A13	11.6	−20	+59

three groups are $\pm 0\overset{''}{.}0011$/year, $\pm 0\overset{''}{.}0013$/year, and $\pm 0\overset{''}{.}0023$/year, respectively. For the first group the radii of the three circles were taken to be 2.5, 4.0, and 6.0 times the mean error, as was done for the stars of Figure 1*A*. The membership classes were made in the same manner. For the second and third groups, no class 1 membership was given. The adopted radii for the second group are 2.5 and 5.0 times the average mean error; and for the third group, 2.5 and 4.0 times the average mean error. In both cases stars falling within

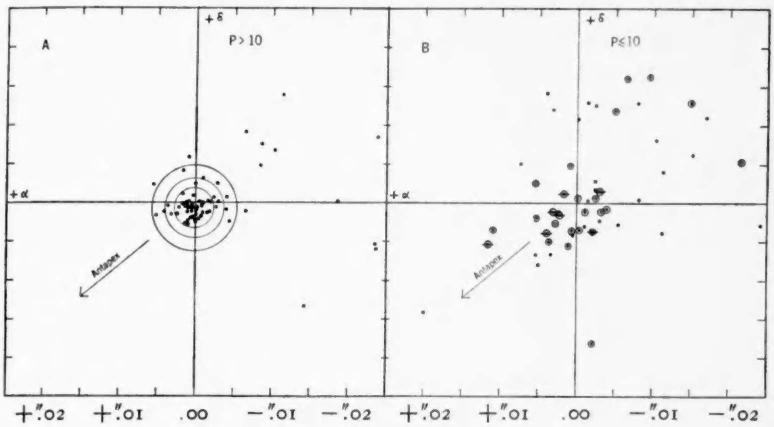


FIG. 1

the inner circle were given class 2 membership. The number of stars which were rated as belonging to classes 1 and 2 is 62.

Figure 2*A* is a plot of the positions in the cluster of all stars whose weights are > 10, and Figure 2*B* gives the positions of all stars whose weights are ≤ 10. In both plots the circled dots are those with a cluster membership of class 1 or class 2. It will be noticed that the cluster members do not show any marked concentration toward the center in the region discussed. The concentration of the stars in Figure 2*B* toward the outer regions of the cluster is largely due to the fact that not all of the plates had the same center.

Of considerable interest are Figures 3*A* and 3*B*, which show the spectrum-magnitude diagram. Figure 3*A* is the same as that published by Kuiper in his discussion of the hydrogen content of clusters;[3] it contains all the stars with known spectra. The ordi-

[3] *Ap. J.*, **86**, 176, 1937.

nates are apparent bolometric magnitudes, and the abscissas are log T_e. The same temperature scale was used as in Kuiper's paper.

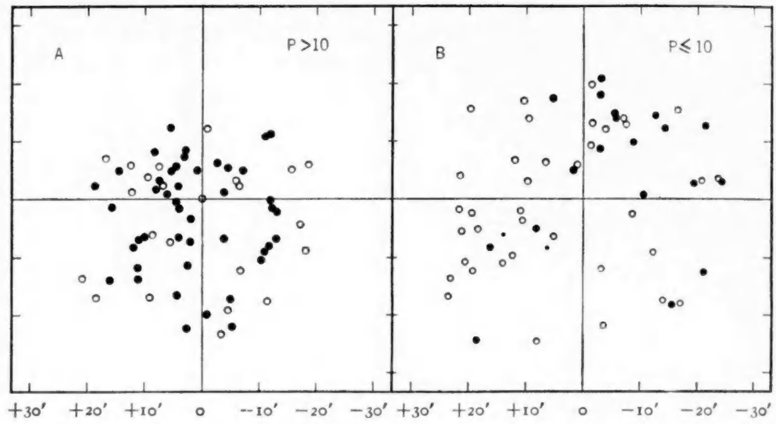


FIG. 2

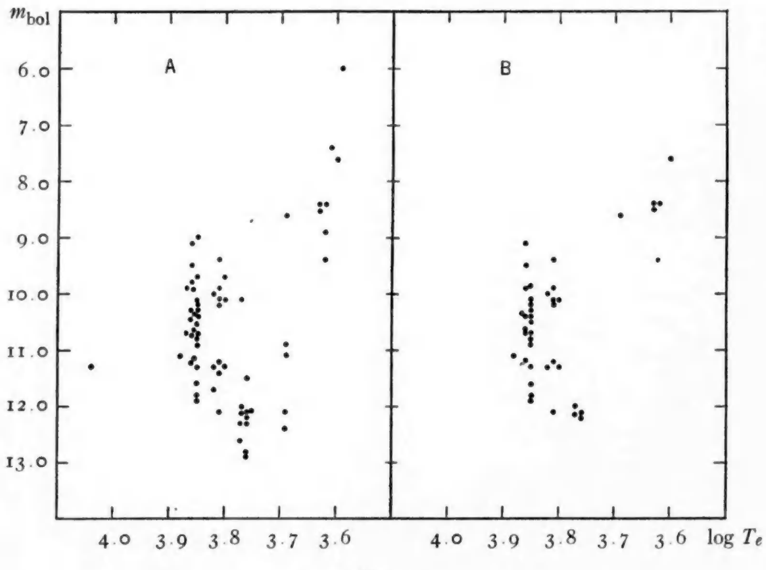


FIG. 3

In Figure 3*B* only stars with a cluster membership of 1 or 2 have been included. The striking difference between the two figures is im-

mediately evident. It is of interest to note that the brightest star in the cluster, No. 215, is probably not a cluster member, although this conclusion is rendered somewhat uncertain because the magnitude equation for this star had to be extrapolated.

It is of interest to use the preceding results in the study of the luminosity function of the cluster. The data suffice for the derivation of this function for photographic magnitudes. The result is given in Figure 4. The maximum around $m_{pg} = 10.2$, and the relatively small number of faint cluster members are noteworthy. The

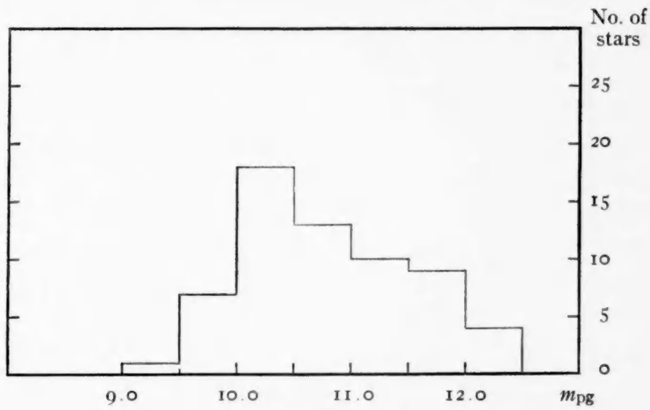


FIG. 4.—Luminosity function for NGC 752

distance modulus of NGC 752 is about 8.0. Hence the absolute photographic magnitude of the maximum is about $+2.2$, which differs greatly from that found for stars in general and for other galactic clusters.

IV. THE ABSOLUTE PROPER MOTION OF THE CLUSTER

Unfortunately, no cluster members are contained in the *Boss General Catalogue*. In Schorr's *Eigenbewegungs Lexikon* motions are given for 14 cluster members. The proper motion of the cluster derived from these stars is $\mu_\alpha \cos \delta = +0\overset{''}{.}005$/year $\pm 0\overset{''}{.}004$ (m.e.) and $\mu_\delta = -0\overset{''}{.}010$/year $\pm 0\overset{''}{.}005$ (m.e.), or $0\overset{''}{.}011$/year $\pm 0\overset{''}{.}005$ (m.e.) in position angle about 158°. As a result of the rather large mean error of this determination, the value is not very significant.

An attempt was then made to determine the absolute motion from

the measures of the faint stars on P I. The proper motion of the cluster relative to 55 stars between photographic magnitude 13.0 and 13.9, inclusive, was found to be $\mu_\alpha \cos\delta = +0''.002$/year and $\mu_\delta = -0''.009$/year. In this mean, two stars of exceptionally large motion were omitted (Nos. 175 and 286 in Table 4). If these two stars are included, the motion of the cluster becomes $\mu_\alpha \cos\delta = 0''.000$/year and $\mu_\delta = -0''.011$/year. For stars of mean photographic magnitude equal to 13.5 and at 23° from the galactic plane Oort gives[4] the mean parallax as 0''.0017. The antapex is 90° from the cluster in position angle 129°. The galactic co-ordinates of the cluster are $l = 105.4$ and $b = -22.7$; and at this position the galactic rotation effect is about $-0''.003$ in galactic longitude, or very nearly $\mu_\alpha \cos\delta = -0''.003$/year. Hence, the absolute proper motion of the cluster becomes 0''.012/year in about 160°, which happens to agree very well with the value determined from meridian positions. The motion of the cluster, omitting the galactic rotation term, is about 0''.014 in 147°, but most of this is the reflex of the solar motion, which is 0''.010 in 129°. Therefore, corrected for solar motion, the true transverse motion of the cluster is about 10 km/sec.

Grateful acknowledgment is made to Dr. R. J. Trumpler and Dr. K. Burns, who have taken the first- and second-epoch plates, respectively. The writer wishes to express his sincere thanks to Director Jordan for having made the plate material available. The writer is further indebted to Dr. Trumpler for his permission to use his spectral types for this cluster. I wish to express my thanks to Dr. Kuiper for having suggested this problem and for his general guidance.

Yerkes Observatory
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[4] *B.A.N.*, **8**, 90, Fig. 3, 1936.

VARIATIONS OF GRAVITY AT ONE PLACE

O. H. TRUMAN

ABSTRACT

This paper deals with a four months' series of gravity observations made at Houston, Texas, with an instrument having a probable error for one reading of about 0.00002 cm/sec^2. There are slow apparent changes depending upon the weather, a diurnal and a semidiurnal change depending upon the sun, and periods depending upon the tidal effect of the moon in distorting the earth or in shifting water on it. These are discussed at length.

There is no proof of any variation arising from the earth's absolute motion through space, and none is to be expected unless from a much longer series of observations.

In 1932 the writer made a portable gravity meter, for use in locating oil-bearing structures, which was successfully operated in the field for about two and a half years, in the region of the western Gulf Coast of the United States. It proved to perform with very gratifying accuracy and reliability. In the last months of its service, during the hours of the day when not in practical use, it was read regularly in the hotel rooms, wherever it happened to be; and the results were plotted. They showed such interesting variations from time to time that it was decided to set up the machine, as soon as opportunity afforded, in a permanent location and to carry on, with every possible care and refinement, a series of several months' observations, night and day.

The opportunity to do this came in the winter of 1936/37. The writer enlisted Mr. R. B. Douglas to help him, and with his aid observations were kept up in Houston, Texas, for 4 months, at intervals mostly of $1\frac{1}{2}$ hours throughout the day and 2 hours in the middle of the night. The following paper deals with the results.

A few scattered observations have been published by W. D. Wyckoff,[1] and a long and very careful series by Tomaschek and Schaffernicht.[2] The latter series gave such unexpected results that it was, for that reason alone, worth while to supplement it on a wholly different part of the earth's crust.

The gravity meter used by the writer operates on the spring and

[1] Nat. Res. Coun., *Trans. Amer. Geophys. Union*, Part 1, p. 48, 1936.

[2] *A.N.*, No. 5844; *Ann. d. Phys.*, **15**, 787, 1932; *Zs. f. Geophys.*, Heft 4/5, p. 199, 1933.

suspended-weight principle, with a device by which the effective length of the spring is greatly increased, so as to bring the deflections due to small changes of gravity up to the point where they can be successfully magnified by the optical-lever principle to such a degree that they can be read. The machine was invariably read by a null method, a line in the field of the eyepiece, which moves with variations of gravity, being moved by a micrometer screw acting upon a very weak auxiliary spring until it was upon a fixed line of a scale; and then the changes of gravity were obtained from the screw reading. Because of the almost incessant motion of the movable line to and fro, owing to microseisms, this method is much better than trying to estimate the position of this line at varying points along the scale. In fact, in this way the microseisms, which would otherwise be an evil, actually help the accuracy of reading, provided they are no larger than is common at the Gulf Coast.

Temperature is, of course, one of the great enemies in designing such an instrument. To prevent errors due to it, the instrument proper is inclosed in a heavy nonconducting case, in which the temperature is maintained very closely by a thermostat, at a point a few degrees above the highest expected air temperature. The temperature of the instrument, as shown on a Beckman thermometer, fluctuates a few hundredths of a degree, partly in a daily cycle, depending upon changing outside temperature; but these changes have been ascertained, by separate tests, to be wholly without effect upon the readings. They will be gone into more thoroughly below, in connection with the 24-hour wave.

In the instrument as used in the field, no attempt was made to keep the case airtight, since to make it so and to be sure it stayed that way would involve a great deal of trouble. Instead, air-pressure changes were merely corrected for. But in the accurate work to be done here, it was an essential that the uncertainty of these corrections should be entirely removed. At the same time, it was not desired to completely rebuild the machine with a new airtight inner case and new outer cases, etc., which this would have necessitated; instead, the whole apparatus was put inside an airtight case.

It will be seen that, if this alone were done, the pressure inside the instrument would change with varying room temperature, since a

rise of temperature would expand the air outside the insulating case and force some of it into the constant-temperature space. Also, small leaks are always to be apprehended. It was easiest to overcome all the troubles, therefore, by adding an electrically operated pressure-regulator, which would constantly hold the pressure about 50 mm of mercury below the average outside pressure, and therefore always somewhat below the lowest outside pressures which might occur.

This pressure-regulator had a mercury column which balanced the inside pressure against a Torricellian vacuum. Whenever the pressure rose, it broke an electrical contact in the mercury, which, through relays, started a small pump and pumped it down again. By providing a small leak, which constantly admitted a little air, together with what might get in through accidental leaks, the absolute pressure inside was kept the same, day after day. It might seem that there would be a pressure cycle, owing to intermittent operation of the pump; but by proper proportioning, this was kept down to a point where it could not be detected with certainty by a microscope on the mercury, and was certainly no more than 0.02 or 0.03 mm—far too little to matter. Also, by properly choosing the long and short legs of the pressure-regulator, it can be made immune to varying temperature of the mercury and glass. This was done by calculation; and it was later verified, by special tests, that room temperature had no effect upon the gravity readings.

The objection can be raised to this procedure that the moisture content of the incoming air will vary from time to time, thus gradually changing the moisture content of the air in the case; and it can be calculated that the resulting change in indicated gravity might become very important, although it would only occur slowly over a period of several days. To test this, ingoing air was alternately fed for several days through a bubbling water bottle, which must have caused it to be saturated with moisture, and through a calcium chloride bottle, which, with the slow rate of passage of air through it, must have dried the air entirely. Repeating this test several times showed, very gratifyingly, that there was no visible effect upon the gravity readings; and it can only be believed that the calculated effect spoken of above was in some way compensated.

The instrument was set up in one of the rooms of an ordinary brick-veneer dwelling-house. By bracing the floor underneath securely with small concrete piers, vibration and changes of level due to people moving about were entirely done away with. The instrument was releveled before each reading, by means of sensitive levels; and, needless to say, proper tests had shown that these levels would check the position with the required accuracy. Disturbances due to traffic were wholly unimportant.

Such a gravity meter is, however, a pretty sensitive seismometer, even though its sensitivity as such is purposely minimized as much as possible by the design. In this case a ground movement up and down of 0.0005 mm would cause a motion of a whole division in the eyepiece, a very perceptible amount. However, most of the time in the Gulf Coast the motion is only two or three of these divisions and, as was stated before, aids, rather than lessens, the accuracy. Earthquakes were very noticeable, when they occurred; and several times they made it necessary to suspend the observations.

One fact was observed, however, which ought to be mentioned, as it may be an important contribution to the question of the origin of microseisms. During the winter time the Gulf Coast is often visited by "northers." A norther is a period of very cold weather, with a high wind from the north, frequently initiated by the passage of a "squall line" or "wind-shift line," and may or may not be accompanied by rain. Now during these northers the ground motion may increase to as much as forty or more of the eyepiece divisions, often compelling the suspension of work. There is never any ground motion of importance excepting with a norther; it is never caused by a wind from any direction, no matter how high, unless coming with a norther. And a norther always brings ground motion.

It is thus evident that microseisms at the Gulf Coast are in some way caused by some peculiar conditions accompanying northers. The writer understands that in Europe they have been thought to be due to the pounding of the waves upon the rocky coasts of Norway at times of storms at sea; but in view of the above-mentioned observation, it seems much more probable that they are caused by something else accompanying the storm, and that the pounding of

the waves is merely incidental. On the Gulf Coast the shores are mostly low and gently sloping, and the high winds which accompany a norther would be offshore winds.

The instrument was originally intended to measure gravity with a probable error of a little less than a "point," a "point" being the unit in which all work with it has been done, and being equal to 0.0001 cm/sec^2, or 0.1 milligal. (This unit was chosen because the milligal was too large.) When set up for stationary use, however, it performed much better. The agreement among readings can be approximately judged by Figure 1, which shows a representative series covering $2\frac{1}{2}$ days at new moon, when the tidal effect is at its

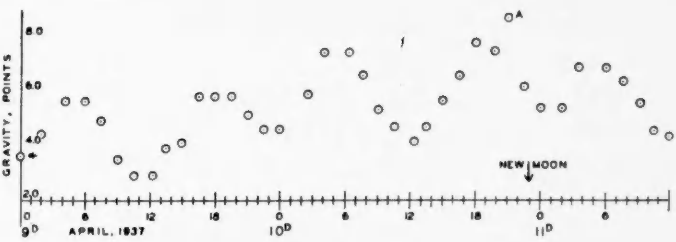

FIG. 1.—Specimen series of observations

greatest. Lengthy investigations of the observations have shown more accurately that the probable error of one reading is about 0.2 point. Occasionally there were readings, such as Figure 1, *A*, which differed from the others by amounts seemingly out of proportion to the regular accidental errors and which, as in this case, were checked and found not to be due to mistakes. The cause of these is unknown. In the reduction of the results no reading was rejected merely because it differed from the others, but readings made during bad northers were not used.

With these preparations, observations were carried on from December 18, 1936, to April 21, 1937, the instrument being read every $1\frac{1}{2}$ hours from 6:00 A.M. to midnight, and every 2 hours to 6:00 A.M.

REDUCTION OF READINGS

When this instrument is first put into operation, a drift sets in which gradually ceases and which must be subtracted. This drift is

probably exponential; but it can be represented with sufficient accuracy by a hyperbola, which is easier to compute. Such a curve was, therefore, taken out, from December 18 to March 9, after which, and indeed for some time before, it had become immaterial. This drift is due to some of the materials in the instrument accommodating themselves to a new temperature level.

With this removed, the next most outstanding performance is an irregular drift, which goes in one direction or the other for several days, sometimes covering a range of 35 points, and frequently of 10 or 12, before reversal. A little of it is seen in Figure 1. Very curiously, the onset of a drift downward (in the direction of less force of gravity) almost invariably coincides with the coming of a norther. Among fifteen instances, there is only one where a norther brought about an increase of gravity; and there is only one decrease of gravity, and that a very moderate one, unconnected with a norther.

One would at once attribute this performance to the effect of moisture in the inflowing air (discussed on p. 447) were it not that the experiments described would seem to rule such a cause entirely out. Inasmuch as a norther is usually accompanied by a rising barometer, that is, by more air above the observer, the change is in the direction which would be caused by the attraction of this air reducing that of the earth. But it can be computed that the entire attraction of the air over and about the point of observation is only 4.2 points, and hence that any possible variation of its attraction would be much too small. Moreover, in such a case the changes of gravity should closely follow changes in the barometer, whereas, with the precautions which have been described, even large changes of the barometer bring no changes of gravity which can possibly be attributed to them.

In this connection one is reminded of the slow drifts, one way or the other, of the water in Michelson and Gale's water-filled pipes.[3] It is evident that their experiment was, in many of its aspects, closely related to this. But it is not possible to follow the correspondence in detail. At present, it seems to the writer as difficult to believe that this irregular drift is due to instrumental causes as to believe that it is not, and he must leave the explanation for the

[3] *Ap. J.*, **50**, 330, 1919.

future. For present purposes it was removed by plotting the observations on a large scale (1 inch = 2 points) on long sheets of paper and by drawing a smooth curve through them, using French curves of slight curvature, so as not to affect what follows.

SHORT-PERIOD CHANGES

With these slow changes disposed of, there remain those of a period of a day or less; and these will now be investigated.

The most prominent is, of course, that due to the direct tidal force of the sun and moon, which stands out so plainly in Figure 1. Instead of analyzing for the various tidal periods, leaving this force in, as was done by Tomaschek and Schaffernicht and in the analogous case of the water-filled pipes by F. R. Moulton,[4] and so obtaining each harmonic component as a sum of the tidal force, of the effects of shifting water in the ocean, and of distortion of the earth, the writer preferred to subtract the tidal force in the first place, thus leaving the unknowns alone to be dealt with. It also seemed easier to calculate this force directly from the formula than to build it up from its harmonic components, as is usually done.

To do this, we have the formula

$$\Delta g = \frac{gmr^3}{MR^3}(1 - 3\cos^2 z) ,$$

where g stands for gravity; m, mass of moon or sun; M, mass of earth; r, radius of earth; R, distance of moon or sun; and z, zenith distance of moon or sun. gm/M is, of course, a constant for either body, and r/R is the parallax reduced to circular measure. Its value is easily calculated with sufficient accuracy by the slide rule, from the figures given in the *Nautical Almanac.* In fact, we have a constant factor, which combines with the other constant, and the cube of the parallax given in minutes for the moon and in seconds for the sun. The hour angle of the sun is the Central Standard Time of observation, plus a slowly changing number, depending upon the longitude and the equation of time. The declination is taken from the *Nautical Almanac;* and these two, together, quickly give the

[4] *Ibid.*, p. 50, 346.

zenith distance by a chart computed for the place of observation. From all this the part of Δg due to the sun, is easily found.

The right ascension of the moon is given in the *Nautical Almanac* for each hour throughout the day. The difference between this and the right ascension of the sun, combined with the hour angle of the sun, gives the hour angle of the moon; and this, with its declination and the chart, gives the zenith distance. With this and the parallax the lunar part of Δg can be found. This process was checked by exact calculation in a few cases and was found amply accurate.

The total Δg for sun plus moon, computed for each 2 hours, was plotted, and a smooth curve was drawn from which the value could

TABLE 1

Symbol	Name	Amplitude (in Points)	Period (in Hours)
M_2	Principal lunar	0.567	12.4206
S_2	Principal solar	.264	12.0000
N_2	Larger lunar elliptic	.110	12.6584
K_2	Lunisolar	.072	11.9672
K_1	Lunisolar	.375	23.9345
O_1	Larger lunar	.268	25.8193
P_1	Larger solar	0.124	24.066

be taken off for any desired time. This was then subtracted from the observations, together with the irregular drift, and the results were plotted on a large scale. They contain the unknown short-period effects, which are to be investigated by harmonic analysis.

The most prominent, and one obvious at sight in the earlier months, is a period of 24 hours, with its maximum (greatest increase of downward force) about 6:00 A.M. In addition, from tidal theory we have the tidal components shown in Table 1, some of which might be expected to cause perceptible effects by their distortion of the earth or otherwise. The amplitudes (half of the total range) are computed for Houston, and their periods are in mean solar hours.

It is well known that, in analyzing for any period, such a time interval should be chosen as is not only an exact multiple of that period but also, as nearly as possible, an exact multiple of all the periods near it. In that way the intrusion of the latter periods into

the result desired will be kept at a minimum. In this case, analyzing for the 24.0000-hour period, 28 or 29 days will almost exactly contain the 25.8193-hour period, and thus the latter will be very nearly eliminated. As for the other two, K_1 and P_1, they will, over such an interval, combine into a single quasi-period of 23.966 hours, which cannot be eliminated effectively from an interval of 28 days' observations, and only partly from one of four months. This matter will be taken up at greater length below, in connection with the special interest which attaches to the period of 23.9345 hours, or one sidereal day.

THE 24.0000-HOUR PERIOD

Turning then to the 24.0000-hour period spoken of above, it is analyzed in the form $y = a \cos(\theta - \alpha)$, where the intervals, a and

TABLE 2

Interval	a (in Points)	α	a' (in Points)	α'
(1) Dec. 19.0–Jan. 17.0.......	0.500	90°8	0.487	173°7
(2) Jan. 17.0–Feb. 15.0.......	.397	96.3	.400	156.3
(3) Feb. 15.0–Mar. 15.0.......	.342	81.0	.282	124.5
(4) Mar. 15.0–Apr. 12.0.......	.201	94.6	.255	69.3
(5) Mar. 24.0–Apr. 21.0.......	0.244	82.1	0.294	54.8

α, are given as in Table 2. The fifth interval, while largely overlapping the fourth, is put in for what it may be worth and in order to include all the readings.

At the same time, the calculated tidal effect of sun plus moon is analyzed in just the same way over the same intervals, and gives the results in columns a' and α'.

In order that the reader may judge the validity of the results, the curves of summed observations and summed calculated sun plus moon are shown for the third interval in Figures 2 and 3, together with their least-squares cosine curves. The plotted points are obtained in the manner well known in harmonic analysis, by taking for 0.0 hour the mean of observations at February 15, 0^h0, February 16, 0^h0, etc., and similarly for 1.5 hours, etc. By means of the large-scale chart spoken of above, of the observations with hyperbolic drift, irregular drift, and calculated sun plus moon removed, the

observed figures could be easily taken off, interpolating when necessary and otherwise leaving a blank (for instance, when too many observations had been missed because of a norther).

It is seen from the figures that there is an obvious 12.0000-hour period in the observations and a very pronounced one in the calculated tide. These also are analyzed by least squares, in the form $y = b \cos(\theta - \beta)$, and the two sets of results are given in Table 3. Columns b' and β' refer to the calculated tidal effect. The waves a' are doubtless due to the quasi-period mentioned above, a combination of K_1 and P_1; and the waves b' to a combination of K_2 and S_2. Each of these combinations, over an interval of a month, will act as one wave.

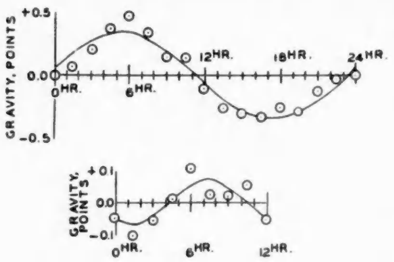

FIG. 2.—Observed gravity, February 15.0–March 15.0, showing 24-hour and 12-hour periods. The calculated effect of the sun and moon has been removed.

Turning now to the 24.00-hour wave, the writer must say that, to him, it is the most puzzling and potentially important of all. Comparing the amplitudes of the observed wave, a, with those of the calculated tide, a', it is seen that they vary so nearly together as to make it seem certain that the latter causes the former, by the distortion of the earth and the shifting of water about upon its surface. But when the angles of maximum, α and α', are compared, it is seen that there is no relationship. While α' continually decreases over a large range, α varies but little on either side of 90°, the variations being probably due mostly to accidental errors. It appears that the observed wave arises from something wholly apart from tidal effect.

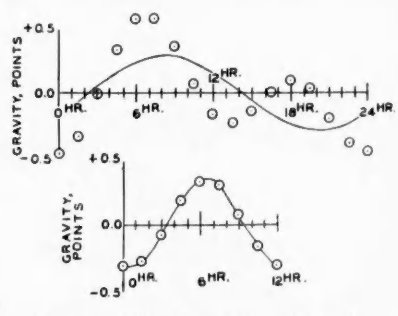

FIG. 3.—The calculated effect of sun *plus* moon, February 15.0–March 15.0.

Such a wave was found by Tomaschek and Schaffernicht and was

called by them S_1. It had an observed amplitude of 0.356 of our points, and an angle of $43^\circ.5$, which would bring its maximum 2.9 hours after midnight, instead of about 6 hours, as observed by us. When these were corrected for the interference of waves near by in period, they became 0.117 and $66^\circ.0$, or 4.4 hours, respectively. They speak of this wave as being identical with the "Wärmeflut" found by horizontal pendulum measures, and state that it is particularly prominent and disturbing in observations made on the surface of the ground. They consider that an important element in the success of their own observations was that they were made deep under a hill.

TABLE 3

Interval	b (in Points)	β	b' (in Points)	β'
1	0.110	$191^\circ.3$	0.227	$199^\circ.5$
2	.073	162.2	.297	200.5
3	.071	221.2	.328	194.2
4	.117	168.5	.313	184.4
5	0.106	195.0	0.303	191.0

It is seen that in the present observations, made on the surface, this wave is strong but not overwhelming.

That any expansion and contraction of the ground by heat should cause such a wave seems to the writer quite impossible, for, in order to cause gravity to vary by the amount required, the ground would have to move up and down over a range of the order of a foot, the exact movement depending upon just how the distortion was distributed. This statement puts this cause quite out of the question. In an instrument so sensitive to tipping, and therefore to small differential motions of the ground, as is the horizontal pendulum, a temperature effect is perhaps conceivable; but this is not the case with an instrument sensitive only to total motions.

The same appears when we consider atmospheric pressure. Curiously enough, when, for the sake of curiosity, the diurnal pressure change in Houston was analyzed for the interval December 19.0 to January 17.0, there was found a 24.0-hour wave with an amplitude of 0.0214 inches, or 0.54 mm, and a maximum at 6^h40^m after midnight, nearly corresponding with the average maximum at about 6 hours, in the gravity wave. (There the 12.00-hour wave was also

found, with an amplitude of 0.0256 inches and maxima at 9^h38^m A.M. and P.M., and a good indication of an 8.00-hour wave, of amplitude about 0.007 inches). But calculation shows that it is quite impossible for such a pressure wave to depress the ground by anything like the amount required. And, more conclusive still, the much larger irregular pressure changes going on all the time have no perceptible effect.

No doubt the 24.00-hour wave will be attributed by many merely to the daily change of temperature in the instrument. In the opinion of the writer, however, this can be definitely ruled out. It is found that the total range of the daily temperature change averaged for the five periods, in centigrade degrees, is as follows: 0.0134, 0.0119, 0.0158, 0.0176, and 0.0225. Thus, in general, the range of temperature change increases as the effect it is supposed to cause decreases. More than that, on one well-marked occasion, while the temperature on the Beckman, through accident, increased by $0^\circ.2$, the gravity, corrected for sun plus moon, did not change by any perceptible amount. As a change of 0.3 point would certainly have been seen, the temperature coefficient is less than 1.5 points per degree; and a range of temperature change of 0.02 degree, a liberal average of the above, would cause only 0.03 point of gravity change.

This 24.00-hour wave in gravity, therefore, remains to the writer a mystery. If it be allowed to combine all the observations, from December 19.0 to April 21.0, despite the very definite decrease of amplitude with the coming of spring, we obtain for the average amplitude 0.364 points and a maximum $88^\circ.6$, or 5.90 hours after midnight, Central Standard Time. As it is to be presumed that the period in gravity is in some way connected with the sun, the position of the sun at this time should be noticed. Taking account of the difference between Central Standard and true local time over the whole interval, which varies over a range of 17 minutes because of equation of time, we have, as the average hour angle of the true sun at maximum gravity, 261°, or nearly 270°, which is very strange.

THE 12.4206-HOUR PERIOD

We can now turn to the principal lunar period of 12.4206 hours, which, in the latitude of Houston, is the largest of all the tidal terms,

with an amplitude of 0.567 points, as seen in Table 4. It is found that a time interval of 56 cycles will be most effective in rejecting other periods near it, and the analysis is made over four of these intervals, as shown in Table 4. As before, the primed letters refer to the calculated tidal force and the unprimed letters to the observations. For this analysis the cycle of 12.4206 hours was divided into twelve parts of 30° each. There is no need to analyze the computed

TABLE 4

Interval	c (in Points)	γ	c' (in Points)	γ'
(1) Dec. 19 $4^h.8$—Jan. 17 $4^h.4$	0.150	206°.6	0.579	181°.8
(2) Jan. 17 4.4—Feb. 15 4.0	.093	181.3	....	....
(3) Feb. 15 4.0—Mar. 16 3.5	.077	297.3	....	....
(4) Mar. 16 3.5—Apr. 14 3.1	0.134	222.5	0.570	182.7

sun plus moon for the two middle intervals, and the last was only done as a check. If it be taken that the variations in c and γ are due to errors, then, according to the principles of harmonic analysis, they should be averaged as vectors, not as scalars; and we have as the mean wave of terrestrial origin, of period 12.4206 hours,

$$y = 0.093 \cos (\theta - 218^\circ) .$$

Other workers have measured not this wave but the total effect of it combined with the original gravity wave. If we combine these again as vectors, we arrive at

$$y = 0.648 \cos (\theta - 186^\circ.6) ,$$

so that, if we had analyzed the total change of gravity of period 12.4206 hours, the result should have been as shown above. It is seen to be about 13 per cent greater than for a rigid earth and to lag about 4°.4. Michelson and Gale found a lag of 4°, as a mean, in their water-filled pipes, which agrees well with that found here. Their measured tide in the pipes was, in the mean, 0.69 of that computed, which agrees in sense with the foregoing, inasmuch as any spring or distortion of the earth would make their results less and these greater. Wyckoff got an average lag of about 50 minutes of time,

from all the waves combined, in which, however, waves of about 12-hour period played a predominant part. Fifty minutes in a 12-hour period would be 25°, totally different from the above. Tomaschek and Schaffernicht obtained from the 12.4206-hour wave a total effect of only 55 per cent of that computed, with a lag of about 42°, which is again wholly different.

However, it should not be surprising if different results are obtained upon different parts of the earth's crust, since the earth might yield differently in different directions. Unfortunately, however, the whole matter is so complicated by the possible effect of shifting water in the oceans that it is hard to see how anything of value respecting the actual distortion of the earth can be secured when the anomalous gravity changes are as small as appears to be the case. It can be computed that, if a great circle were described upon the earth with the observer at its pole, and 1 foot of water were taken from a zone 20° wide, centering along this circle, and distributed between the zones of 20° radius centering about each pole, which would raise the level in each by 2.9 feet, then, provided the observer were himself on land, so that there was no water added nearly underneath him, the change of gravity would be +0.0556 point. It thus appears that, when we are dealing with variations as small as one- or two-tenths of a point, the oceanic tides can exercise an important influence, and one that could not be disregarded unless ruled out by accurate and detailed calculations. The difficulty of these, considering the complex shape of the oceans and our very fragmentary knowledge of what the tides away from land actually are, need not be emphasized.

THE 12.0000-HOUR PERIOD

Comparing now the results of 12.0000 hours and those for 12.4206 hours, it is seen that they are quite different. The average earth tide is about twice as large, compared to the attraction supposed to produce it, and leads by an average of about 9°, rather than lagging. At first sight, this seems to invalidate the whole investigation, as it would be supposed that two waves so nearly alike in period would behave substantially the same. When we reflect, however, that the 24.00-hour observed wave had nothing to do with the corresponding

wave of attraction of sun plus moon, it is not strange that the same should hold good with its first harmonic. We merely see that causes are acting in a period of 24 hours and its submultiples, of which we know nothing.

When the 12.00-hour observed waves are averaged vectorially, we find a wave $y = 0.090 \cos(\theta - 186^\circ)$, thus having maxima at 6.2 hours A.M. and P.M. The hour angle of the true sun at this time will average about 265° and 85°, respectively.

THE 25.819-HOUR PERIOD

Since the wave of a 25.8193-hour period has (from Table 1) a considerable amplitude, and since it should be well separated from

TABLE 5

Interval	d (in Points)	δ	d' (in Points)	δ'
(1) Dec. 19 $9^h.4$—Jan. 16 $8^h.7$..	0.032	25°.6	0.276	194°.5
(2) Jan. 16 8.7—Feb. 13 8.0..	.030	64.9	....	....
(3) Feb. 13 8.0—Mar. 13 7.4..	.077	204.1	....	....
(4) Mar. 13 7.4—Apr. 10 6.7..	.120	156.0	0.244	197.6
(5) Mar. 24 1.5—Apr. 21 0.8..	0.207	146.6	....	....

all the others of nearly a 24-hour period, it seemed worth while to analyze for it. The results are given in Table 5, unprimed letters again referring to the observed wave, caused by earth distortions or other terrestrial influences.

It is now seen that, while the attraction wave varies but little throughout the whole time, as it should, the terrestrial wave changes greatly. The small amplitudes in the first two intervals are so much affected by errors that no reliance can be placed upon their exact value; but while all the errors are larger in this series than in most of the others, there seems no doubt that the terrestrial wave had a very small amplitude at the beginning and built up as time went on. Thus it appears that these terrestrial effects not only vary from place to place on the earth's surface but from time to time at the same place.

This terrestrial wave sometimes lags, sometimes leads, its supposed cause; and in general the two have little relation to each other.

THE 23.9345-HOUR PERIOD

This period of one sidereal day deserves particular attention, because any variations of gravity owing to the absolute motion of the earth and solar system through space would be expected to follow either it or its first harmonic of 11.9672 hours. In fact, Courvoisier thought he had obtained proof of such effects,[5] although their reality seems to have been disposed of by Tomaschek and Schaffernicht. However, it is worth while to obtain from these observations whatever may be possible, bearing upon this matter.

Over an interval of only four months, a period of 23.9345 hours will gain only about 120° upon one of 24.0000 hours. Thus, in making a direct harmonic analysis for either, the result will contain a great deal of the other. But by analyzing for each period, we obtain a vector with two components, or four components in all; and as each of these components contains the four components of the two vectors we seek, the latter can be derived from the former by the solution of four simultaneous equations.

The observations were, therefore, analyzed for a period of one sidereal day over the interval from December 19, $0^h.6$, to April 21, $9^h.0$ ($123\frac{3}{4}$ cycles), using sixteen steps of 1.5 sidereal hours each in each cycle. The averages run very closely upon a curve whose least-squares equation is

$$y_s = 0.310 \cos (\theta - 131^\circ.2) .$$

The 24.0000-hour wave over the interval December 19, $0^h.0$, to April 21, $0^h.0$ (123 cycles), gives an equation

$$y = 0.364 \cos (\theta - 88^\circ.6) ,$$

which, as we have seen, is the average of results which vary over a considerable range, from month to month.

When now the simultaneous equations are formed and solved, we obtain

$$y = 0.294 \cos (\theta - 54^\circ.9) ,$$

$$y = 0.450 \cos (\theta - 121^\circ.2) ,$$

[5] *A.N.*, **226**, 241, 1926; **230**, 245, 1927; **234**, 137, 1928; **237**, 337, 1930; *Phys., Zs.* **28**, 674, 1927.

as the equations of the true 23.93- and 24.00-hour waves, respectively, each unmixed with the other. The beginnings of the two cycles were chosen to coincide on December 28, $0^h.0$.

Thus, taking this at its face value, we have a true 24.00-hour wave whose maximum comes not at about $6^h.00$ A.M., as heretofore, but at about $8^h.00$ A.M. And we have a 23.93-hour wave whose amplitude, 0.294 points, is so large a fraction of the tidal component of 0.375 points (p. 452) that the latter could hardly be regarded as the sole cause of the former; and we should look for some additional cause, depending upon the absolute motion of the earth through space.

However, it is very doubtful whether we can take these at their face value. When the foregoing "true" waves are combined for each of the separate intervals used originally in analyzing for the 24.00-hour wave, they do, indeed, cause the amplitudes and phase angles to vary in somewhat the way there found; but the allowances which have to be made for errors or other causes are so great that results considerably different from the foregoing would have brought about as good an agreement, and the whole case must be set down as not proved. If any variation of gravity in a period of a sidereal day is to be found with any reliability, it will take observations over a whole year to do it.

It is worth remarking that, when the averaged observations at 0.0 and 12.0 sidereal hours were added and divided by 2, and the same was done for 1.5 and 13.5, and so on, so as to separate the wave of period 0.5 sidereal day for the two intervals

Dec. 19, $0^h.6$—Feb. 18, $20^h.5$ (62 cycles)

and

Feb. 18, $20^h.5$—Apr. 21, 9.0 ($61\frac{3}{4}$ cycles)

separately, and plotted, the former interval showed a pretty definite period with a maximum at about 6 hours, and the latter one with a minimum at about the same time. As the amplitudes in either case were only about 0.06 or 0.08 points, their reality is doubtful. At any rate, over the whole time they canceled out, showing in the mean, therefore, no period of half a sidereal day.

SUMMARY

Analysis of the observations shows:

1. An apparent variation of gravity over an interval of several days, amounting sometimes to as much as 35 points, or 0.0035 cm/sec^2, connected with changes of the weather. Despite some evidence to the contrary, this must probably be set down as due to instrumental causes, in the absence of positive proof.

2. A pronounced variation in a period of 24.0000 hours, and a small one in a period of 12.0000 hours, both arising from some unknown effect of the sun.

3. A definite variation in a period of 12.4206 hours, caused undoubtedly by distortion of the earth and shifting of water about upon its surface, owing to the tidal force of the moon.

4. A variation in a period of 25.8193 hours, corresponding to the larger lunar diurnal tide but increasing from month to month during the observations. That a component of constant amplitude in the moon's attraction should cause an effect upon the earth which is not constant but varies from time to time is of itself an important point and adds to the difficulty of interpreting the measures.

5. No proof of any change of gravity in a period of a sidereal day, and none to be expected except from observations extending over at least a year.

November 1938

212 Canyon Road
Salt Lake City, Utah

NOTES

NOTE ON THE EXPLANATION OF THE D-LINES IN THE SPECTRUM OF THE NIGHT SKY

The observation of the D-lines of sodium in the spectrum of the night sky, and with greatly increased intensity in the twilight and dawn skies, is now a well-established fact.[1,2] The most probable source of the sodium appears to be the evaporation of *NaCl* from sea water,[2,3] though the mechanism for dissociating the *NaCl* at these heights (greater than 60 km) appears to be in some doubt.[4]

It is therefore worth pointing out that the resonance lines of the alkalis are observed in the laboratory when alkali halides are irradiated with ultraviolet light.[5] The process involved is a photo-dissociation into a normal halogen and an excited alkali atom; thus the D-lines are observed in emission though free sodium atoms in a concentration which would give observable absorption are not present. The absorption spectrum of the alkali halides is continuous, with several maxima of absorption. The two maxima of longest wave length correspond to the dissociation into a normal alkali and a normal and excited halogen atom. Successive maxima are proved to produce the dissociation into a normal halogen and an alkali atom in the first, second, etc., excited state. For example, for *CsI*, six maxima have been observed with frequency differences corresponding to iodine $^2P_{1/2} - {}^2P_{3/2}$ and to caesium $2P - 1S$, $3D - IS$, $2S - 1S$, and $3P - 1S$. For *NaCl* only the first two maxima have been observed (at 2370 and 2320 A). The maximum corresponding to the P state of sodium falls outside the region observed in the laboratory—around 1700 A (calculated by adding 16,950, the wave number of the D-lines, to

[1] Cabannes, Dufay, and Gauzit, *Ap. J.*, **88**, 164, 1938.

[2] Bernard, *Ap. J.*, **89**, 133, 1939.

[3] Duffieux, *Bull. de la Soc. Sci. de Bretagne*, **15**, 1 and 2, 1938.

[4] Russell, *Sci. Amer.*, **160**, 88, 1939; but see also Duffieux, *loc. cit.*, and Bernard, *C.R.*, **206**, 1669, 1938.

[5] A general discussion and summary is given in Finkelnburg, *Kontinuierliche Spektren*, p. 173, Julius Springer, Berlin, 1938.

the wave number of the maximum of longer wave length mentioned above). The absorption region will extend at least two or three hundred angstroms toward longer wave lengths; thus, the region of absorption of sunlight for this process extends beyond the strong oxygen absorption. Dissociation during the night could be attributed to electron impacts.

In the absorption process discussed there would be an excess of energy (*a* in Fig. 1) which as kinetic energy would cause line broadening. Thus, a determination of the width of the D-lines in the sun-

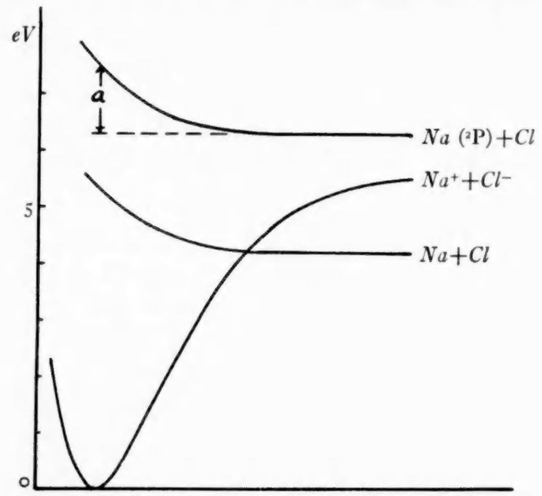

FIG. 1.—Potential curves of *NaCl*. The ordinates are energies in electron-volts; the abscissae are inter-nuclear distances.

lit evening or dawn sky would furnish information on the region of absorption of sunlight for this process. Only low dispersion spectrographs can be used in photographing the night sky, and the D-lines have been separated only by the addition of an interferometer. However, the identification, together with a measurement of the width, can easily be accomplished by placing a tube containing sodium in front of the spectrograph and by varying the pressure of sodium by known amounts until the D-lines in the night sky are completely absorbed.

JAMES FRANCK
CAROL ANGER RIEKE

DEPARTMENT OF CHEMISTRY
UNIVERSITY OF CHICAGO
March 1939

REVIEWS

Œuvres choisies. By CHARLES FABRY. Paris: Gauthier-Villars, 1938. Pp. vi+695.

Professor Fabry has recently celebrated his *jubilé scientifique,* in connection with his seventieth birthday, and it is therefore appropriate that this magnificent volume of his most important papers should have been printed as a testimonial to the many scientific advances which we owe to him. The volume is arranged by subjects: Part 1 deals with interference phenomena, Part 2 with various problems in optics, Part 3 with electricity, Part 4 with photometry, Part 5 with astrophysics and geophysics, and Part 6 with instruction and popularization. Finally, Part 7 gives a complete bibliography.

Some of the papers have not previously been published, but most of those which are of interest to astronomers have originally appeared in the *Journal de physique,* the *Astrophysical Journal, Comptes rendus,* etc. Among these are the classical studies of the Orion nebula by means of a Fabry-Perot interferometer, the papers on the illumination of the night sky, on the equilibrium temperature of a body exposed to radiation, on the scattering of light by gases, on the energy-curve of the sun, etc.

Professor Fabry has, since 1906, been one of the collaborating editors of the *Astrophysical Journal.* It is, therefore, with particular pleasure that we join his many friends in extending to him our congratulations and wishes for many happy and productive years of research.

O. S.

Kontinuierliche Spektren. By W. FINKELNBURG. Berlin: Julius Springer, 1938. Pp. 368. Rm. 33.

The study of line spectra and discrete atomic energy states has received considerable attention in recent years, resulting in the collection of a great deal of data and the development of a theory altogether successful in explaining the wave lengths of spectral lines. The more recent interest in continuous spectra differs from the earlier study of line spectra mainly in two respects: (1) the study of continuous (classical) energy states is combined with quantum theory, and (2) more emphasis is thrown on the theory and measurement of intensities or transition probabilities in contrast to wave lengths.

In this book Dr. Finkelnburg presents both of these aspects with praiseworthy precision and completeness. Valuable in itself is an extensive bibliography of some seventeen hundred references to astronomical, physical, mathematical, and chemical journals. In addition, the "Namenverzeichnis" and "Sachverzeichnis" help to make the book a valuable source for any spectroscopist.

The subject matter is well ordered in the text, starting from fundamental theory and definitions of terms. Excellent care is shown in treating the latter—a great boon, in view of the myriads of overlapping terms used in the literature. For example, a brief derivation is given, in chapter i, of the formulae connecting various definitions of the absorption coefficient with oscillator strength, transition probability, and the matrix elements of wave mechanics, all of these being measurements of the same physical entity.

It is not easy to find gaps in the subject matter. So complete is the treatment, in fact, that line broadening is included—perhaps a little forcibly—as being a special case of a continuous spectrum over a small range. Chapter headings cover the broad fields of fundamental wave-mechanical and radiation theory, photo-ionization and recombination, "electron switches" or "free-free transitions," molecular spectra, line widths, black- and grey-body radiation, and laboratory procedure necessary for observing various types of spectra. Each field is quite completely developed in a logical way from basic theory through predictions to applications and experimental results. With the possible exception of the sections dealing with wave mechanics, no special knowledge is demanded from the reader.

A good many references are made to astrophysical applications, although the author has fortuitously kept clear of speculations by showing mainly the confirmation (or condemnation) of theory by laboratory measurements. In criticism it may be said only that Dr. Finkelnburg has presented his subject a little too categorically, indicating scholastic, rather than creative, ability. Certainly he has brought together data from widely separated fields of research into a most useful book for the specialist, a most instructive book for the student.

THORNTON PAGE